# *Executive Summary*

## S-1. Introduction

Studies of the possible health effects of electromagnetic fields (EMFs) from the electric power system[1] have been ongoing for almost 30 years. Although scores of studies have been completed on laboratory animals, cells, and human populations, unassailable evidence that EMF exposure is harmful has yet to emerge. In 1998, the National Institute of Environmental Health Sciences convened an expert working group to review studies of possible EMF health effects (NIEHS, 1999). This panel concluded that magnetic fields from power systems should be classified as possibly carcinogenic, on the basis of a number of epidemiological studies showing elevated risks of leukemia among children and workers exposed to unusually high magnetic field levels. The panel stopped short of characterizing the EMF-leukemia link as probable or proven because laboratory animal and cellular-level studies have not supported the observations in human populations. The panel further concluded that evidence linking EMF to diseases other than leukemia was either weak, sparse, or non-existent. This leaves open the possibility that diseases other than leukemia might be influenced by EMF exposure, although it may be quite some time before enough research is completed to permit experts to render a judgment one way or the other.

Public concern about possible EMF health risks has prompted government authorities to sponsor public information and research programs directed at improving understanding of the biological effects of EMFs. In 1993, the California Public Utilities Commission (CPUC) instructed the public utilities in California to support an EMF research and public education program (CPUC decision 93-01-013). The CPUC authorized the California Department of Health Services (CDHS) to carry out this program. The studies undertaken by this program (see http://www.dhs.ca.gov/ehib/emf/) address a range of scientific and public policy questions. This report addresses one of those questions: What are the pros and cons of alternative policies to address EMF exposure in California public schools?

The California EMF Research Program has focused on schools for several reasons. First, of all the diseases that have been studied in relation to EMF exposure, the evidence for EMF-induced childhood leukemia risk is strongest, although not considered conclusive by scientific review panels (NIEHS, 1999; NRC, 1999). Second, society has historically set high standards for safety in schools and has shown a higher willingness-to-pay to protect children than to protect adults. Finally, the public school environment,

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[1] Power system EMFs arise from many indoor and outdoor sources including appliances, lighting fixtures, building wiring, transmission and distribution lines, electrical panels, and transformers. Although the term “electromagnetic field” technically refers to both electric and magnetic fields, concern about health effects has focused almost exclusively on exposure to magnetic fields. In this report, we use the term “EMF” to refer only to magnetic fields.

unlike many other environments (e.g., home, work) is government-managed, so government agencies have a more direct institutional responsibility to manage EMF risks in schools compared to EMF risks in other areas. Occupational risks incurred by teachers and other school staff, although not the main driving force behind interest in EMF in schools, are also a consideration in the decision to study the EMF-in-schools problem.

The overarching goal of this project is to help policy makers and stakeholders evaluate alternative statewide policies to address EMF exposure in public schools. The project has four main products. The first (this document, containing this Executive Summary and a main report) identifies policy options at the statewide level and describes alternative frameworks for analyzing the pros and cons of those options. The second, a computer model called EMF_SCHOOL, allows stakeholders and decision makers to explore the statewide costs and benefits of magnetic field standards for schools (Florig, 1999 #4). The third, a brief orientation to using the first two products in actually making decisions. The fourth, a report on the social costs of a variety of diseases possibly associated with EMF exposure (Sheppard et al., 1998), provides background information to support analyses in the first two products.

This Executive Summary presents the key points of our analysis of statewide policies for addressing EMF risks in schools. We begin with a summary of pertinent EMF exposure and risk information. We then describe various criteria by which alternative approaches might be judged, as well as the different world views that different stakeholders tend to favor in framing policy decisions. We discuss various settings under which EMF-in-school problems arise and we analyze a number of possible engineering and procedural policy options to address each of those settings. Finally, we review ways in which policy options might be funded.

## S-2. EMF Exposure

Sources of magnetic fields within school buildings include electrical and electronic equipment, lighting fixtures, building wiring, electrical panels, and outside power lines. A recent survey by Enertech Consultants, Inc. of magnetic fields in a sample of 89 public schools[2] in California found that field levels in classrooms average about 0.5 mG, but vary greatly both within and between classrooms (Zaffanella and Hooper, 2000). Figure S-2-1 shows the estimated number of classrooms statewide with average magnetic field levels that exceed a given value. Of the 268,300 public school classrooms in California, it is estimated that 700-4,200 have room-average field levels exceeding 5 mG.

[2] Enertech's measurements in a sample of 89 California schools are used in this report to extrapolate conditions for all 7,800 schools in the State as a whole. There are obvious uncertainties associated with this extrapolation that the reader is asked to keep in mind.

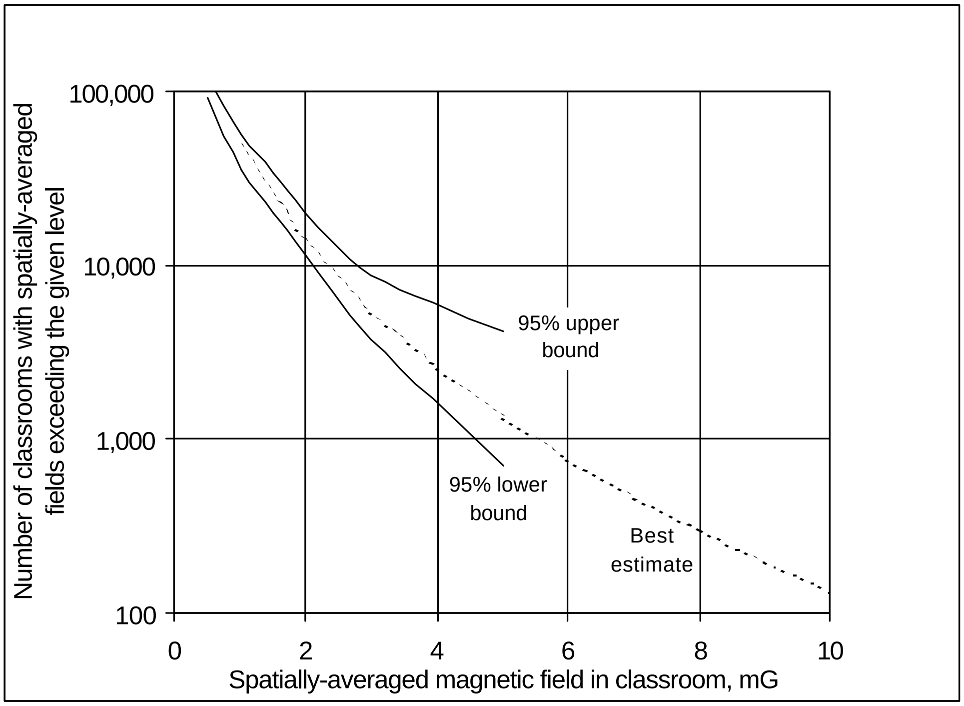


*Figure S-2-1. Number of classrooms statewide with spatially-averaged magnetic field levels exceeding a given value. Adapted from Zaffanella and Hooper 2000. Best estimate for fields greater than 5 mG obtained by fitting data from Zaffanella and Hooper to a lognormal distribution. The uncertainty in the number of classrooms with average fields in the 5-10 mG range is quite large.*

Magnetic field levels in schools are not significantly different from those in homes. A study of magnetic field levels in 1,000 homes across the U.S., also conducted by Enertech, found average household fields to be slightly greater (0.6 mG) than the average fields in California classrooms (Zaffanella, 1993). Measurements conducted as part of a recent epidemiologic study of magnetic field exposure and spontaneous abortion in California found averages of 0.95 mG for indoor spot measurements in the homes of 506 women controls (Lee et al., 2001).

Another Enertech study measuring 24-hr personal exposure of 1,012 quasi-randomly selected individuals in the U.S. found time- and population-average exposures of 1.25 mG (Zaffanella and Kalton, 1998). Personal exposure measurements on a sample of 28 teachers in California schools yielded time- and population-average exposures of 1.02 mG for teachers working in a school near a 69 kV transmission line (N=13) and 0.69 mG for teachers working in a school without nearby power lines (N=15) (Lee et al., 1999). Personal exposure measurements made in conjunction with the spontaneous abortion study mentioned above found 24-hour time-weighted averages among 483 controls of 1.43 mG.

By far, the largest contributor to <u>classroom-average</u> magnetic field levels in schools are net currents in school wiring (Table S-2-1). Net currents result primarily from wiring errors, which cause supply and return currents in building wiring to flow along different paths. In addition to elevating magnetic field levels, such wiring errors can also increase risks of fire and electric shock. Enertech's measurements show that net currents are the dominant field source, contributing roughly 70% of the EMF exposure (measured in classroom-mG) in classrooms with average fields exceeding 0.5 milliguass (see Table 8.39 in Zaffanella and Hooper 2000 ). Distribution lines are the next most important contributor to average field levels, contributing about 10% of exposure (classroom-mG) above 0.5 mG. Net currents are also the most common cause of unusually high magnetic fields in classrooms, accounting for 86% of the classrooms in which average fields exceed 5 mG (see Figure S-2-2). Transmission line classrooms (i.e. classrooms with transmission line fields > 0.5 mG in at least 5% of the area) have higher average fields than classrooms affected by other sources, but the number of classrooms affected by transmission lines is small compared to the number of classrooms affected by many other sources.

*Table S-2-1. Number of classrooms statewide with spatially-averaged magnetic fields exceeding 0.5 mG and 2 mG, and total classroom magnetic field exposure from different sources. There are 268,000 classrooms in the entire state. Total classroom exposure in units of classroom-milligauss is estimated by multiplying the number of classrooms in a field-strength category (e.g., 1-2 mG) by the midpoint field strength of the category (e.g., 1.5 mG) to obtain the classroom-mG for that category. Then the classroom-mG for all categories are added to get the total. Data on number of classrooms by source and field level are from Zaffanella and Hooper 2000.*

| Field source | Number of classrooms with average fields > 0.5 mG | Number of classrooms with average fields > 2 mG | Total exposure (classroom-milligauss) |
|---|---|---|---|
| Net current | 64,000 | 11,000 | 99,000 |
| Distribution line | 11,700 | 1,300 | 14,000 |
| Fluorescent lights | 11,800 | 0 | 9,100 |
| Electrical panel | 6,800 | 500 | 7,300 |
| Office equipment | 5,500 | 100 | 6,200 |
| Transmission line | 2,300 | 140 | 3,300 |
| Power cable | 1,950 | 410 | 2,500 |
| Power transformer | 1,700 | 120 | 1,900 |
| Air conditioner | 530 | 0 | 400 |
| Current in water main | 150 | 0 | 100 |
| Total exposure | | | 143,800 |

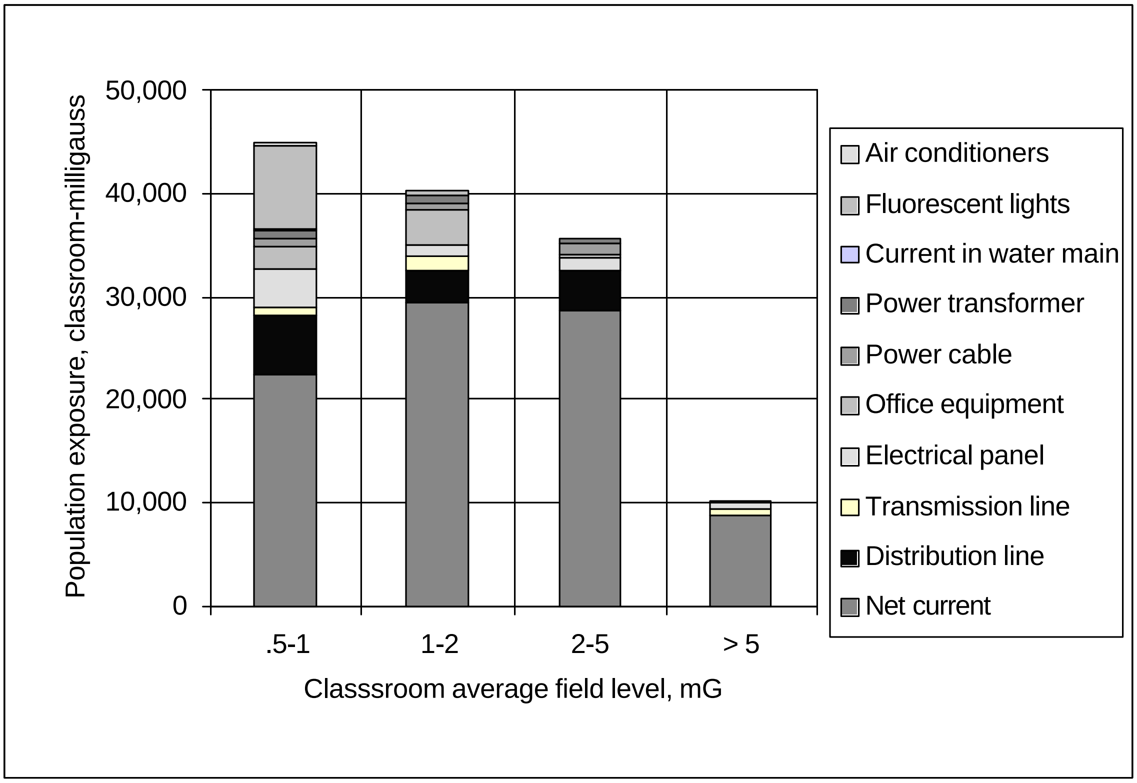


*Figure S-2-2. Pre-mitigation population exposure by source and pre-mitigation spatially-averaged classroom field level. Note that 65% of the classroom-milligauss are contributed by classrooms whose average field is below 2 milligauss and that in all categories, net currents are important contributors. Computed from data in Zaffanella and Hooper 2000.*

## S-3. EMF and other Risks in Schools

**Theoretical EMF Risks**. As noted above, epidemiological studies have associated EMF exposure with a variety of rare and common health conditions. The decision models we have developed allow the decision maker to assign degrees of confidence of causality and effect sizes to all of these. The NIEHS working group assigned a "possible cause" to childhood leukemia, one of the rarer conditions. Since there is a published estimate of the theoretical population burden and added annual risks among the most highly exposed children, we will compare this theoretical added risk to other health risks in schools and discuss the implications of this comparison. In a recent meta-analysis of magnetic fields and childhood leukemia, Greenland and colleagues concluded that household magnetic field exposures averaging 3 mG and above convey an additional annual leukemia risk 1.7 times that of exposures averaging 1 mG or less (Greenland et al., 2000). Given background mortality rates for leukemia in California school children of 16 deaths per million per year (where field levels at home and school average 0.5 - 0.9 mG), annual excess leukemia risks among those with home exposures averaging 3 mG and above would be roughly 11 deaths per million.

School children spend less than 20% as much time in school as in their home. If, as we assume in our models, that the weighted average of home and school time exposure best predicts disease risk, then the magnetic fields in schools would presumably convey a smaller excess risk to any given individual than equivalent fields at home (say 20% of 11 per million per year). Alternatively, if we consider the possibility that chronic exposure to the same magnetic field level at school and at home produce the same health effect regardless of the fact that the time spent at school is less than the time spent at home, then the results of Greenland et al. would imply excess leukemia risks of roughly 11 deaths per million among those exposed at school to fields exceeding 3 mG. Note that 1-3% of classrooms in California (2,700-8,000 classrooms) have spatially-averaged magnetic fields exceeding 3 mG. Many thousands of other classrooms have at least 5% of floor space (the equivalent of one desk's location) with fields exceeding 3 mG.

**Non-EMF Risks.** It is useful to compare the potential EMF leukemia risks of the most highly exposed students (perhaps 2 excess deaths per million per year for school-time exposures of 3 mG and above) with the well-established non-EMF risks that children face. Considering both school and non-school time, the overall mortality risk for school children is about 250 per one million per year, with automobile accidents contributing the largest portion. A recent compilation of risks to middle school children (Florig, 2000 #10) estimated that annual mortality risks are roughly 70 per million for commuting to/from school, 20 per million for accidents at school (except sports), 10 per million for infectious diseases contracted at school, 8 per million for team sports activities, and 2 per million for intentional injury (i.e., violence). Thus, even for those school children exposed to the strongest EMF fields in the classrooms, it seems likely that EMF leukemia risks would be comparable to or smaller than other school and non-school risks that they encounter.

These comparisons of EMF and non-EMF risks in school have implications for risk management that we discuss in detail later in this report. Briefly, those who subscribe to a “worst risks first” approach to risk management would argue that effort should be devoted to reducing the larger, non-EMF school risks before investing in EMF mitigation. Those who advocate using cost-effectiveness to allocate resources for risk reduction would call for studies of the efficacy and costs of addressing non-EMF risks, before making any investments to mitigate risks at schools. For example, how many of the 2 per million violent deaths each year could be eliminated by employing metal detectors and guards in each school and what would be the cost per violent death avoided? Others, who are more concerned with the distribution of the total risk burden among schools, would argue that resources should go first to those schools bearing the greatest risk from all sources combined. Still others would focus on the deaths that seem most unjust regardless of cost, hence the current focus on the 2 per million violent school deaths and not on the 20 per million accidental deaths.

## S-4. Policy Criteria

There are six major criteria that most people would consider in evaluating the merits of a given policy option for managing possible EMF risks in schools. These are exposure reduction, costs, ethical implications, legal and organizational compatibility, administrative effort, and adaptability to future changes in knowledge.

Exposure reduction includes exposure reductions for both the most exposed individuals and for the population as a whole. Costs include investments in magnetic field surveying, source diagnoses, and mitigation measures. Ethical considerations include who will pay and who will benefit from a policy, as well as issues of fairness, restitution, and responsibility. Legal and organizational compatibility refers to the degree to which a given policy fits with existing legal and organizational structures. Administrative effort includes measures needed by government authorities to implement and enforce the policy. Finally, adaptability to new knowledge is the extent to which a policy is compatible with alternative outcomes of research on EMF bioeffects.

Of these six criteria, consideration of ethical dimensions is the most challenging. Social scientists find that equity and fairness issues are often central to many environmental policy disputes, yet equity and fairness issues are rarely treated explicitly in the policy-making process. Ignoring the resulting undercurrents makes it more difficult for decision makers to understand stakeholder positions, and can lead to unnecessary rancor. We therefore explicitly address these issues in this report.

Opinions about who should benefit from and who should pay for magnetic field management in schools can be expected to differ depending on one's ethical world view. Ethicists have identified three main world views to which different people adhere, although not necessarily consistently. *Libertarian justice* holds that property and other individual rights are supreme. Libertarians have a *laisez faire* approach to managing risks that are voluntarily undertaken or that result from activities with direct benefits to those at risk. Libertarians would demand redress of risks involuntarily imposed by another party. Thus, libertarians might accept EMF exposures from hair dryers, but not from transmission lines unless they are compensated. Under Libertarianism, the costs of EMF exposure reduction would be paid for either by (i) everyone equally (ii) only those willing to pay, (iii) those responsible for the equipment creating the exposure, or (iv) only those with children in school.

*Utilitarian justice* seeks the greatest good for the greatest number. Utilitarians support any measure that increases the average welfare of the population. Thus, utilitarians would support reductions in EMF exposure that could be achieved at modest cost per unit of exposure reduction, but would reject exposure reductions with high costs. Utilitarians would reject measures that single out any particular source (e.g. power lines) for mitigation, arguing that all sources should be considered together to find the most cost-effective opportunities for exposure reduction. Given the uncertainty concerning the existence of EMF health effects, utilitarians might forego EMF reductions altogether in favor of using risk-reduction resources to manage some known hazard to school children. Under Utilitarianism, the costs of EMF exposure reduction would be paid for by the wealthy, since they would suffer the least utility loss per unit expenditure.

*Social justice* seeks to reduce the burden of the worse-off, regardless of the cost to the average welfare. Thus, social justice advocates would first address EMF risks in poorer school districts, in schools where the burden of non-EMF risks (e.g. violence) is high, or among individuals with high personal exposure to EMF. Under social justice, the costs of EMF exposure reduction would be paid for by everyone except the poor.

Table S-4-1 summarizes how the targets and funding mechanisms of EMF policy for schools might differ under different prevailing ethical worldviews.

*Table S-4-1. Implications of ethical worldview for policy choice on EMF in schools. Libertarian justice elevates property rights above all others. Utilitarian justice transfers risk and cost to achieve the greatest good for the greatest number. Social justice protects those who are worst-off from losing even more.*

| Issue | Libertarian justice | Utilitarian justice | Social justice |
|---|---|---|---|
| Whose exposure will be reduced? | Those most able to pay<br>Those most concerned | Those for whom exposure reduction benefits are commensurate with costs | Those most exposed to EMF<br>Those most exposed to non-EMF risks<br>Those least able to pay |
| What sources will be controlled? | Whatever each district prefers.<br>Those not under the child's control or those from which the child receives no direct benefit | Those for which exposure reduction is most cost-effective | Sources in disadvantaged districts. |
| What exposure reduction policy? | Information only, with interpretation and implementation left up to each district. | Adopt all field reduction measures that meet some cost-benefit or cost-effectiveness criteria. | Reduce all exposures below some threshold of acceptable risk. Threshold might vary with SES and health of population. |
| How to fund? | Costs paid by all, those willing to pay, those whose equipment creates exposure, those with kids in school. | Costs paid by wealthy to minimize social utility loss, since the marginal value of income is greatest for the poor. | Costs paid by all except the poor. |

## S-5. Decision Settings and Management Options

The EMF-in-schools problem is quite broad, encompassing decisions at statewide to local scales involving a variety of procedural, ethical, legal, economic, and organizational issues. To make our analysis tractable, we limited our analysis to those policy setting and management options that we judged to be of most interest to the public, to the electric utility industry, and to various state agencies. These settings and options were identified through a series of interviews with a variety of stakeholders, and through discussions with the Stakeholder Advisory Consultants.[3]

Decision settings addressed in this analysis focus on the statewide level, or perhaps at the level of a large school district. In this document, policy alternatives are analyzed for the following situations:

- New school construction with and without existing power lines nearby
- New power line construction or modification near an existing school
- Existing schools with and without existing power lines

A number of exposure reduction and procedural options are considered for these decision settings. We consider eight options for reducing possible EMF risks. These are listed below and described fully in the main body of the report.

1. Eliminate existing EMF programs (Section 5.1.1). These include existing siting rules for new schools near power lines and no-cost/low-cost guidance for new power line projects.

2. Maintain the status quo, continuing existing EMF programs such as the public communications program run by CDHS (Section 5.1.2).

3. Prohibit increases in EMF exposures from power lines near existing schools (Section 5.1.3).

4-6. Implement magnetic field strength, personal exposure, or technology-based standards (Sections 5.1.4 to 5.1.6).

7. Enforce some provisions of the National Electrical Code in new and/or existing schools, or otherwise reduce sources of net current in school wiring (Section 5.1.7).

8. Address EMF as part of a program to address all health and safety risks in schools (Section 5.1.8).

We also consider the following five procedural options:

1. Develop information programs to help school officials respond to concerns of parents and teachers (Section 5.3.1).
2. Elicit citizens' views concerning value choices in EMF policy decisions (Section 5.3.2).
3. Standardize and integrate siting guidelines for schools and electrical facilities (Section 5.3.3).
4. Include EMF in the CPUC's CEQA review (Section 5.3.4).

[3] The California EMF program has established a group of Stakeholder Advisory Consultants (SAC) to provide

5. Make EMF technical services more available to schools (Section 5.3.5)

## S-6. Evaluation of Exposure Reduction Options

We organized the evaluation in terms of the six policy criteria described in Section S-4. While much depends on the specific methods used to implement each option, consistent patterns did emerge from the comparison of all options across each of the policy criteria.

### S-6.1 *Potential for Exposure Reduction*

In terms of exposure reduction, improved information produced under the status quo option has the potential for improving the effectiveness of existing exposure reduction efforts. However, the statewide impact of this improvement will probably be low, since local exposure reduction efforts would remain largely at the discretion of decision makers in the 800 school districts of California. Prohibiting increases in fields around existing power lines will have little impact on exposures in schools, given that the majority of elevated fields are due to internal sources. This option could have community-wide impacts if additional capacity needed to be constructed elsewhere to compensate for the loss in growth potential on existing lines near schools. Under some scenarios, the consequences of such a policy might be a net increase in population EMF exposure from the transmission and distribution network as a whole. The exposure reduction potential for options to set field or personal standards depends entirely on the level at which standards are set. In theory, these options have the potential for substantial exposure reduction, assuming standards are set at a low level. Enforcing the electrical code within classroom buildings has a substantial potential for reducing exposure because this would directly address the most important source of elevated fields in schools, net currents. In addition to reducing magnetic field exposure, enforcing the electrical code reduces risk from electrocution and fire.

### S-6.2 *Costs*

Costs of the various options could include any or all of the following:

- administrative costs for the implementing agency to both promulgate and enforce the policy
- administrative costs for schools and other organizations to interpret and implement the policy
- information gathering costs, often paid to consultants, for surveys, analysis, and design.
- capital or construction costs to effect any needed changes in electrical system design or hardware.

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feedback on project directions and products.

- space usage costs, for cases in which the space has been allocated to a lower-valued use (for example, a highly-exposed classroom has been converted to storage space).

Under the status quo, the majority of costs are borne by individual school districts, although utilities can and have provided technical assistance on a case-by-case basis at their discretion. Costs of preventing increased exposure from existing lines include primarily survey and monitoring expenses and the possible stranded capital costs of unused capacity on existing lines. The statewide costs of implementing magnetic field standards vary widely by source, with net currents having the highest statewide costs and transmission lines the lowest. These statewide costs depend on both the number of schools affected by a given source and the average cost per school to reduce the field from that source. Per school affected, it is more expensive to reduce fields from transmission lines than to reduce fields from net currents. However, since there are many more schools affected by net currents than are affected by transmission lines, the statewide costs of reducing net current fields is higher than the statewide costs of reducing transmission line fields. Based on cost estimates compiled by Enertech Consultants[4] (Zaffanella and Hooper, 1998; Zaffanella and Hooper, 2000), the statewide costs to survey and repair all net current sources producing more than 2 mG average field in any one classroom would be in the neighborhood of $16 million, or an average of about $5,300 per school affected. Costs of personal exposure and technology standards are difficult to predict because they depend entirely on the standards selected for implementation. However, personal exposure standards might be inexpensive if the standards can be met with modest changes in usage patterns of classroom space. For a given expenditure on exposure reduction, standards that require the universal application of a particular technology will yield lower exposure reductions than either field-strength standards or personal exposure standards. This is because technology standards would require some action in all classrooms, regardless of existing field levels or occupancy rates, whereas field-strength and personal exposure standards would require mitigation only in some classrooms. Finally, we note that the most significant non-EMF risks in schools are those from commuting to school, accidents in schools, intentional injury, and infectious diseases. We are aware of no studies of the costs or cost-effectiveness of reducing non-EMF risks in schools, however, there may be numerous low-cost approaches to mitigating such risks (e.g., scheduled hand washing in elementary grades to reduce infectious disease transmission (Master et al., 1997)).

### S-6.3 *Equity and Fairness*

Implications for equity, fairness, and environmental justice are complex and these issues are often central to many environmental policy disputes. Because of their often qualitative and subjective nature, they are rarely treated explicitly in the policy making process, even though ignoring them can make it more difficult for decision makers to understand stakeholder positions, thus leading to unnecessary rancor. To organize this analysis, we identified six specific criteria of fairness that are useful in evaluating and comparing alternative policies:

- *aggregate welfare* - redistribute costs and benefits to maximize the resulting aggregate welfare of society (cf. Bentham's utilitarianism)
- *contribution* - redistribute costs and benefits in proportion to individuals' or groups' contributions to them (cf. Aristotelian ethics, libertarianism, other rights-based principles)
- *need* - redistribute costs and benefits in proportion to need (egalitarianism of outcomes, not merely of rights and opportunities)
- *compensation* - redistribute costs and benefits to compensate those who are either worst off in general or most disadvantaged in a particular domain (Rawls' maximin principle)
- *equality* - impartial, even-handed dealing in which all are treated without distinctions or preference. Equal net benefits for all.
- *acceptable* - outcomes that are accepted by all as fair or "envy free."

Our point-by-point examination of the eight exposure reduction policies showed that their perceived fairness impacts depend to a large extent on the predominant source(s) of exposure, how policies are implemented, and which of the six criteria stakeholders weight most heavily. For example, requirement to pay for expensive mitigation to meet field standards where exposures are only slightly above standards will be perceived as undesirable from a utilitarian perspective.  And first implementing policies related to transmission and distribution lines would violate the contribution fairness criterion if in fact most exposure stems from internal sources. For all policies, the aggregate welfare criterion would also be violated to the extent that efforts to implement this policy impeded efforts to address more severe health risks in schools.

We view environmental justice as a subset of broader fairness concerns. Environmental justice includes several types of fairness, including contribution, equality, and acceptance. The concept of contribution fairness underlies the goal of avoiding exposures that are out of proportion to minority communities' use of or benefit from potentially toxic activities. Equality fairness underlies the desire that minority communities be treated equally with other parts of society and acceptance fairness underlies the premise that minority communities should have the right to accept or refuse the siting of potentially harmful activities. Finally, the emphasis on full and open access to decision-making processes reflects the importance of procedural fairness in environmental justice.

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[4] Enertech Consultants combined results of a detailed survey of EMF levels in 89 California schools with estimates of unit costs to reduce magnetic field exposures from various sources to compute the statewide costs of meeting various field-strength targets in schools.  Their methodology is detailed in Zaffanella 2000.

### S-6.4 *Legal and organizational compatibility*

Actions needed to implement all eight exposure reduction options fall well within the existing authority of key agencies (Table S-6-1).

*Table S-6-1. Summary of agency roles in implementing exposure and risk reduction options. CPUC-California Public Utility Commission, CDE = California Department of Education, LD= Local districts, CDHS = California Department of Health Services.*

| Option | CPUC | CDE | LD | CDHS | Legislature |
|---|---|---|---|---|---|
| 1. Eliminate programs | rescind 93-11-013 | rescind siting guidelines | implement | make finding of no risk.<br>recommend that programs be eliminated. | rescind siting guidelines |
| 2. Status quo | oversee 93-11-013 | continue to enforce siting guidelines | implement | monitor research<br>provide tech support | |
| 3. Prohibit increases | choose level & enforce | | implement | | |
| 4. Field strength standard | choose level & enforce<br>authorize rate-payer share of cost | identify level | implement | make recommendation | enact CDE standard<br>provide state $ |
| 5. Personal standard | | identify level | implement | make recommendations | enact CDE standard<br>provide state $ |
| 6. Technol. standard | set and enforce standards | set standards | implement | make recommendations | enact CDE standard<br>provide state $ |
| 7. Enforce electrical code | | make policy | implement | make recommendation | enact CDE policy<br>provide state $ |
| 8. Address all risks | | establish program | implement | make recommendations | enact CDE policy<br>provide state $ |

### S-6.5 *Administrative effort*

We identified four components of administrative effort at the statewide level: planning, standard setting, rule making, and compliance. While these costs are likely to be small relative to the costs of surveying, diagnosis, and mitigation, other research strongly suggests that the administrative structures of regulatory programs, independent of their cost, can have a large influence on the acceptance of a program and the degree to which it is readily complied with. Such structures will depend on the detailed implementation pathways chosen for any option and are impossible to predict. However, the level of administrative effort involved in each option can be ranked in relative terms, using the status quo as a baseline, as shown in Table S-6-2.

*Table S-6-2. Relative differences among policy options in terms of the key components of administrative effort. Policies are compared on a qualitative scale, with 0 lowest and 3 highest.*

| | Component of Administrative Cost | | | |
|---|---|---|---|---|
| **Options** | **Planning** | **Standard Setting** | **Rule Making** | **Compliance** |
| 1. Eliminate programs | 1 | 0 | 0 | 0 |
| 2. Status quo | 0 | 0 | 0 | 0 |
| 3. Prohibit increases | 2 | 1 | 1 | 1 |
| 4. Field standards | 2 | 2 | 2 | 3 |
| 5. Personal standard | 3 | 3 | 2 | 3 |
| 6. Technology standards | 2 | 2 | 2 | 2 |
| 7. Enforce electrical code | 1 | 0 | 0 | 2 |
| 8. Address all risks | 3 | 3 | 3 | 3 |

## S-6.6 *Adaptability*

Knowledge about the potential health effects of EMF is evolving. Future changes in knowledge can affect our degree of certainty that EMF exposure is hazardous as well as assumptions about what aspect of exposure (e.g., time-weighted average, high-frequency content) best predicts risk. Thus, policy decisions made today (including that of inaction) may, in light of future understanding, seem less than optimal. Some policy options are less forgiving than others in that they cannot be readily changed or reversed in light of new knowledge. Investments in modifications to power lines or building wiring, for instance, are permanent, whereas changes in how space is used are not. Thus, technology-based standards are among the least adaptable, whereas personal exposure standards, which can use rotation of student seating and classrooms, are among the most adaptable.

## S-6.7 *Comparison of Exposure Reduction Options*

The above attribute-by-attribute discussion of exposure reduction options is presented in tabular form in Table S-6-3. Here, we provide a brief option-by-option analysis.

<u>Eliminating existing EMF programs</u> would clearly make sense if scientific consensus were reached that EMF exposures are harmless. Such consensus is unlikely to happen however, given the current weight of epidemiologic evidence suggestive of a health effect, and the tendency of epidemiologic investigations to generate occasional controversial results. In the absence of substantial scientific consensus that EMF

exposure is innocuous, eliminating existing EMF programs may be politically impossible and ethically undesirable. Eliminating existing programs would save the costs of those programs (insofar as they affect schools). These costs are difficult to estimate because there are no data on the costs of compliance with either the School Siting Guidelines or CPUC 93-11-013. Eliminating existing programs would have only a small impact on population exposure to EMF in schools. This is because existing programs affect only a very small number of schools. Nonetheless, eliminating existing programs would convey some additional risk under the possible and definite risk scenarios. Eliminating existing EMF programs would require action by a number of state agencies as well as the State Legislature. These actions could be precipitated by a finding by CDHS that EMF exposure poses no significant risk.

<u>Maintaining the status quo</u>, by definition, incurs no additional costs and accrues no additional benefits compared to existing activities. This policy leaves decisions on EMF avoidance up to local officials, thus wealthier districts are more likely to take action. This policy leaves open the possibility of future action should evidence on EMF hazard become more compelling. In addition, since this policy involves relatively modest investment in exposure control, it largely avoids the risk of sunk mitigation costs, should EMFs be exonerated in the future, or should current mitigation measures prove ineffective. By definition, this policy requires no changes in law or in administrative procedures.

<u>Prohibiting increases in EMF exposure from power lines near schools</u> would require sending power along alternative routes that do not pass by schools. This may require construction of additional power line capacity. Moreover, the power added to alternative routes will itself result in magnetic field exposure to the general population, including school children. This exposure may exceed that avoided by restricting magnetic fields of power lines at schools. Although there may be specific schools and neighborhoods for which the particular power system and housing configurations would make this option a cost-effective alternative, a statewide prohibition on increases in EMF from power lines near schools is inferior to other statewide options that would address EMF exposures from power lines (e.g., a technology standard requiring low-field configurations for those segments of power lines that pass schools). Finally, as power lines are responsible for only a small fraction of magnetic field exposure at schools, this policy alone would have little effect on statewide population risk from schooltime EMF exposures.

<u>Implementing magnetic field strength standards</u> would greatly reduce exposures to the most highly exposed individuals at schools. Because the bulk of the population exposure from EMFs at schools is from fields less than 2 milligauss, however, magnetic field standards would have to be quite stringent to make substantial reductions in total EMF exposure at schools. Field strength standards would apply equally to everyone, so no individual would have residual EMF risks that greatly exceed the average risk. The statewide cost of a field-strength standard depends greatly on the field level chosen for the standard, ranging from roughly $15 million for a 5 mG standard (classroom average) to $120 million for a 1 mG standard.

Implementing personal exposure standards has attributes similar to implementing field strength standards. For a given exposure level, however, personal exposure standards would have lower direct mitigation costs than field strength standards, because the personal exposure standard permits moving of people to achieve compliance. Personal exposure standards would be more complicated to administer than field strength standards, however, because one would need to make measurements of occupancy density and duration in various school areas. The implementation costs of this option would grow in proportion to the level of detail at which time-use factors are considered.

Implementing technology-based standards has the virtue of simplicity, because it requires no area-by-area EMF measurements. Although the policy treats all schools equally, older schools may be more affected than newer ones, simply because older schools are more likely to have net currents, the most likely target of a technology-based standard. Because technology-based standards do not take account of actual field levels or proximity of people to sources, they achieve lower field reductions for a given expenditure on mitigation than either field strength or personal exposure standards applied to the same sources. This disadvantage may be offset by the low administrative costs of technology-based standards.

Enforcing some provisions of the National Electrical Code addressing net currents in school wiring would convey a double benefit by reducing both EMF levels and the risk of electrocution and fire associated with improperly configured internal wiring. There are several variants of this option. The most expensive (about $75 million) would involve electrician visits to all schools to find and eliminate all wiring errors, regardless of the field levels they produce. Less expensive options would involve correcting only those errors that create fields above some threshold (e.g., it would cost about $16 million to fix errors creating average classroom fields exceeding 2 mG), or correcting only those errors encountered during routine maintenance of electrical systems. Because this option only addresses EMF from net currents, however, it would leave untreated situations involving exposures to strong fields from other sources, including power lines.

Addressing EMF as part of a program to address all health and safety risks in schools would undertake reduction of both EMF and non-EMF risks in schools in order of their cost effectiveness for risk reduction. Such a policy would result in the greatest total risk reduction for a given expenditure. Although little is known about the cost-effectiveness of measures to reduce non-EMF risks in schools, some measures, such as scheduled hand washing to reduce risk of intestinal illness, are clearly quite inexpensive and effective, while others like metal detectors and police guards are expensive and of uncertain effectiveness. Without further study of the costs of reducing non-EMF risks in schools, it is impossible to say how much priority would be given to EMF exposure reduction under this policy. By prioritizing by cost-effectiveness, this policy may not address situations involving high EMF or non-EMF risks that are very expensive to fix. If

EMF exposure reduction did not receive priority under this policy, the policy might appear unattractive to adherents of the social justice or libertarian world views.

*Table S-6-3. A comparison of eight policy options for addressing EMF exposure in schools.*

| **Policy Option** | **A. Potential for exposure reduction compared to status quo** | **B. Costs compared to status quo** | **C. Ethical implications (distributive fairness)** | **D. Legal and organizational compatibility** | **E. Administrative effort *0 = least 3 = most*** | | | | **F. Adaptability to future changes in knowledge** |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Planning | Standard setting | Rule Making | Compliance | |
| 1.Eliminate existing EMF programs | Small increase in exposure over status quo. | -Elimination of small but uncertain existing costs of compliance.<br>-Perception that the decision is unfair could raise administrative costs. | | <u>CPUC</u>-Rescind 93-11-013<br><u>CDE</u>-Rescind siting guidelines<br><u>CDHS</u>-Make finding of no risk & recommend programs be eliminated<br><u>LEGISLATURE</u><br>-Rescind siting guidelines | 1 | 0 | 0 | 0 | Preserves the option to take action in the future |
| 2. Maintain the status quo, continuing existing EMF programs | Reduction efforts made at discretion of local decision makers | -Most costs borne by individual school districts<br>-Case-specific costs can be quite high | -Would freeze existing situation, with any existing inequalities | CPUC-oversee 93-11-013<br><u>CDE</u>-enforce siting guidelines<br><u>CDHS</u>-monitor research | 0 | 0 | 0 | 0 | -Preserves the option to take action in the future<br>-Wait-and-see approach |
| 3. Prohibit Increases in EMF exposures from power lines near existing schools | -Little impact on school exposure.<br>-May increase exposure along alternative routes | -Survey and monitoring expenses<br>-Possibly millions for new or upgraded lines to reroute power. | Would freeze existing situation, with any existing inequalities | CPUC-identify level and enforce | 2 | 1 | 1 | 1 | -Since loads grow steadily over time, it is easy to make use of stranded capacity again. |
| 4. Implement magnetic field strength standards | -Depends on the level at which standards are set<br>-Substantial exposure reductions for individuals who are most exposed | -Statewide costs increase from roughly $15 million for a 5 mG standard to $120 million for a 1 mG standard. | Treats all schools and all individuals equally | CPUC-identify level or configuration and enforce<br><u>CDE</u>-identify level<br><u>CDHS</u>-make recommendations<br><u>LEGISLATURE</u>-enact CDE standard | 2 | 2 | 2 | 3 | - Involves substantial sunk costs which would not be recoverable. |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 5. Implement personal exposure standards | -Depends on the level at which standards are set<br>-Substantial exposure reductions for individuals who are most exposed | -Compared to field strength standards, direct mitigation costs are less but implementation is substantially more complicated. | Treats all schools and individuals equally | CDE-identify level<br>CDHS-make recommendations<br>LEGISLATURE-enact CDE standard | 3 | 3 | 2 | 3 | - Involves substantial sunk costs which would not be recoverable. |
| 6. Implement technology-based standards | -For the same investment, will yield lower exposure reductions than either field strength or personal exposure standards<br>-No surveys or source id are necessary | -Depends on which sources are targeted<br>-No expense for surveys and source id<br>-Lower administrative costs than for field strength or personal exposure standards<br>-Less economically efficient than other methods | Impose equal requirements on all parties, though older or lower SES schools may shoulder higher costs (e.g., because they have more net currents and nearby power lines). | CPUC-set and enforce standards<br>CDE-set standards<br>CDHS-make recommendations<br>LEGISLATURE-enact CDE standard | 2 | 2 | 2 | 2 | -One of the least adaptable options<br>-Not easily reversible |
| 7. Enforce some provisions of the National Electrical Code addressing net currents in school wiring | -Would eliminate roughly 2/3 of school-time population exposure<br>-Reduces fire and shock hazards, and over-voltage damage to electrical equipment | -Statewide cost to find and repair all net current sources is roughly $75 million. Cost to repair only those creating > 2 mG in classrooms is much less (~$16 M).<br>-Costs could be reduced by testing and repairing net currents only as other electrical work is done. | Treats all schools equally, though older or lower SES schools may shoulder higher costs because they have more net currents per school | CDE-make policy<br>CDHS-make recommendations<br>LEGISLATURE-enact CDE policy | 1 | 0 | 0 | 2 | Reversibility is not an issue, since provisions of the National Electrical Code should be enforced regardless of EMF concerns |
| 8. Address EMF as part of a program to address all health and safety risks in schools | -Depends on extent to which EMF risk reduction is more cost-effective than reducing non-EMF risks. | -Little data on the feasibility or costs of reducing non-EMF risks in schools. | Could be designed to reduce risks in schools with highest background risks, or with most cost-effective opportunities for risk reduction. Attractive under utilitarian framework. Places no weight on "polluter pays" principle. | CDE-establish program<br>CDHS-make recommendations<br>LEGISLATURE-enact CDE program | 3 | 3 | 3 | 3 | Reversibility not an issue since the statewide evaluation of risks would be addressing a much wider range of risks |

## S-7. Evaluation of Procedural Options

The five procedural options listed in Section S-5 are evaluated below in terms of the policy criteria described in Section S-4. Because the procedural options do not include exposure reduction efforts, the criteria related to potential for exposure reduction and costs are not included here. Note that these procedural options are not mutually exclusive and could be pursued in any combination.

### S-7.1 *Equity*

In general, the procedural options all improve fairness by increasing access to information and/or standardizing the treatment of EMF concerns across schools. However, the ways in which these options are funded and/or implemented can have negative impacts on fairness. For example, if utilities end up paying for technical services that relate primarily to internal sources, this would violate the contribution fairness criterion. Similarly, implementing statewide standards may violate the compensation fairness criterion to the extent that schools differ in their ability to pay for compliance and costs are not reimbursed by the state. They may also violate the aggregate welfare criterion if the costs of compliance divert limited school funds from other priorities with a perceived higher value. While none of the options directly address environmental justice issues, they could be implemented in ways that reduce potential environmental justice impacts. For example, information and funding support could be targeted specifically at poorer and/or minority schools.

### S-7.2 *Legal and organizational compatibility*

As with the exposure reduction options, all the procedural options fall well within the existing authorities of responsible agencies.

### S-7.3 *Administrative effort*

Effort involved in developing and adopting the procedural polices is almost entirely administrative, given that they include no engineering mitigation activities but instead focus on information dissemination, planning, rule making, and protocol and standards development. The costs of such administrative policies are more likely to be borne by state agencies responsible for developing legislation and regulation and overseeing implementation and enforcement.

Administrative effort for the procedural policies can be separated into, first, the effort required to define and enact the policy and, second, the effort needed to carry out the policy. For the first category, the policies fall into two distinct groups. Increasing the availability of technical services to schools would require extensive discussion and negotiation among utilities, the CPUC, the CDE, and other interested parties because of the potential high costs involved in implementation. Conversely, developing an information program, conducting research on stakeholder values, and standardizing siting guidelines are all logical outgrowths of existing policies whose enactment would be relatively straightforward. Expanding the CPUC's CEQA review to include EMF would be contentious and time consuming under present circumstances, but perhaps less so if EMF was shown definitively to be a health hazard. For the second category, implementation, costs for all but one of the procedural options are likely to be low, especially when viewed in terms of their marginal contribution to the costs of existing related policies. The one exception is the provision of technical services to schools, which could be costly depending on the kinds and amount of services provided.

### S-7.4 *Adaptability*

The fact that these options are essentially informational and procedural in nature makes them, in principle, extremely flexible and adaptable. All of them could readily be modified through existing administrative procedures, with little or no loss of stranded capital costs, with the exception of the provision of expanded technical services and schools' efforts to comply with EMF design guidelines.

## S-8. Analysis of Field-Strength Standards

Many of the policy options described above are similar in the sense that some investment is made to achieve some reduction in EMF exposure. Thus, the costs and benefits of these options share a dependence on key factors such as the probability that EMF is harmful, the particular diseases assumed to be caused by EMF exposure, the number of schools close to power lines, the unit costs of reducing exposure, and the willingness to pay to eliminate a unit of risk. To gain insight into the sensitivity of policy outcomes to assumptions concerning these key factors, we developed a quantitative cost-benefit model of the exposure standard policy. This model, which we call EMF_SCHOOL, is designed to be used by stakeholders and policy makers.[5] Drawing on data from Enertech's 89-school survey (Zaffanella and Hooper, 2000), EMF_SCHOOL calculates pre-mitigation EMF levels from four prominent sources: net currents, electrical panels, distribution lines, and transmission lines. Together, these four sources are responsible for roughly 90% of classroom-average magnetic field exposures. For a given field strength standard, EMF_SCHOOL estimates the resulting exposure and risk reductions using the assumption that risk is proportional to time-weighted average magnetic field levels. Costs to implement a given standard are computed from Enertech data on unit costs of exposure reduction for different EMF sources. Risk reductions are converted into disability-adjusted life-years and valued using a unit willingness-to-pay that is supplied by the user. EMF_SCHOOL computes both the cost-effectiveness and the net benefit of a given magnetic field standard. The model also estimates the difference in net benefits between implementing a standard now versus waiting until scientific consensus is reached on EMF hazard before making a decision on whether to implement a magnetic field standard. Key results from EMF_SCHOOL are reported below. Note that EMF_SCHOOL is designed to estimate the costs and benefits of field-strength standards applied statewide and cannot be used to analyze options for any particular school.

## S-8.1 *Schools Affected by Field-Strength Standards*

Under a magnetic field standard for classrooms, all 7,700 public schools in California would be required to make measurements of magnetic fields on the premises to ascertain whether the magnetic field standard is exceeded in any classroom. Table S-8-1 shows the approximate number of schools that would have at least one classroom exceeding standards of 1, 2, and 5 mG classroom-average and 95th percentile magnetic fields.[6]

Note that the difference in the number of schools affected by spatial average versus 95th percentile fields is much larger for net currents and electrical panels than for power lines. This is because power lines are typically far enough away from the affected classroom that magnetic fields levels change by less than a factor of two across the dimension of the classroom. By contrast, fields from net currents and electrical panels change much more across affected classrooms.

*Table S-8-1. Approximate number of schools that would be affected by field strength standards applied to each of four sources. There are roughly 7700 public schools in California.*

| **Source** | **Standard for classroom average & 95% field** | | |
|---|---|---|---|
| | 1 mG | 2 mG | 5 mG |
| Net currents | 4000, 6000 | 1800, 5000 | 500, 2000 |
| Electrical Panels | 400, 6000 | 100, 4000 | 0, 1200 |
| Distribution lines | 700, 1000 | 300, 400 | 60, 170 |
| Transmission lines | 300, 400 | 200, 300 | 70, 100 |

## S-8.2 *Risk Reduction from Field-Strength Standards*

There are two major sources of uncertainty in estimating the efficacy of any approach to EMF exposure management. First, as discussed above, scientists don't know whether or not magnetic fields at levels commonly found in schools are actually hazardous. Second, if magnetic fields are hazardous, scientists don't know what aspects of exposure are most predictive of risk. EMF exposures are dynamic.

[5] EMF_SCHOOL runs on either Windows or Macintosh platforms using a decision-analysis software package called Analytica, by Lumina Decision Systems. Copies of EMF_SCHOOL, with a run-only version of Analytica, may be obtained from the EMF Program of the California Department of Health Services.

[6] Enertech's 89-school survey measured magnetic field levels at approximately 120 evenly-spaced locations in each classroom. The classroom-average field level is the average of those 120 readings. The 95th percentile field

Not only do people move through spatially-varying fields, but magnetic fields at any one location may change from moment to moment as a result of changing electrical loads on the power system. Currently available epidemiologic and laboratory studies offer only limited insight into what aspect of someone's personal exposure history will best predict EMF health risk. Although time-weighted average (TWA) magnetic field exposure has been found to be predictive of risk in some studies, other studies suggest that sudden changes in field intensity might be important as well. Still other studies suggest that a field strength threshold might exist below which there are no effects, or that biological effects might accrue only for exposures to fields within some narrow range of field strength (i.e. a "window" effect). Dealing with so many possibilities in a regulatory context is difficult, because actions that reduce one aspect of field exposure (e.g. the time-weighted average) may have only a limited effect on others (e.g. transient content). Thus, it is important for policy-makers to adjust downward estimates of risk reduction that are based on any one measure of exposure, to account for the possibility that other measures of EMF exposure might better predict risk. Given current scientific evidence, judgments of how large this downward adjustment should be are highly subjective. Nonetheless, our model provides an adjustment that the user can supply.

In this policy model, we have assumed individual risk is proportional to the TWA magnetic field strength that the person encounters throughout their home, school, and other environments. The epidemiology on childhood and adult leukemia suggest this, and exposure studies suggest that TWA exposure is well-correlated with other possible exposure measures, such as the amount of time spend above some threshold field strength. Further, information is not available on student/staff patterns of movement within the schools that Zaffanella and Hooper surveyed. This would have been needed to assess the efficacy of mitigation based on an exposure measure other than the TWA. We assume that a person's total EMF risk is the sum of risks from both school-time and non-school-time EMF exposure, and that reductions in school-time magnetic field exposure only affect the former.

By assuming that risk is proportional to TWA magnetic field, we imply that ten people chronically exposed to 10 milligauss have the same group risk as 100 people chronically exposed to one milligauss. Further, we imply that a field reduction from 10 mG to 9 mG will have the same risk reduction as a field reduction from 2 mG to 1 mG. Note that many field reduction measures implemented in response to an exposure standard will affect all classrooms with field levels above the standard as well as some classrooms with field levels below the standard. Both net currents and power lines, for instance, usually affect multiple classrooms. This means that some of the estimated risk reduction from field-strength standards actually comes from field reductions below the standard. Were there actually a field strength threshold for EMF effects, then our risk reductions based on TWA would overestimate the risk reductions associated with a given field strength standard. TWA-based estimates of risk reduction would be particularly suspect for any

level for each classroom is that which exceeds 95% of the readings in the classroom. One can think of the 95th disease that is affected only by brief exposures to very strong fields, as correlations between TWA field level and the occurrence of infrequent high exposures are modest.

In a recent analysis of 12 studies of magnetic field exposure and childhood leukemia, Greenland et al. (Greenland et al., 2000) conclude that if residential magnetic field exposures have any effect at all, they might be responsible for roughly 3% of all childhood leukemia cases in the U.S. Greenland was assuming a threshold of around 3 mG. In California, there are about 200 new cases of childhood leukemia per year among school-aged children, of which, under Greenland et al.'s conclusions, about 6 cases per year would be attributable to residential EMF exposure. Since children are exposed to EMF for fewer hours at school than at home, however, the number of cases attributable to school-time exposure would be smaller still, assuming a 24-hour TWA exposure measure. Of these remaining few cases per year that are attributable to school-time exposure, only a fraction of those can be eliminated using field-strength standards, since such standards only eliminate a fraction of all school-time EMF exposure. Using estimates from Zaffanella and Hooper (2000) of the number of classrooms with magnetic fields exceeding a given level, it is estimated that classroom-average field-strength standards of 1 mG, 2 mG, and 5 mG would eliminate 50%, 27%, and 6% of classroom average EMF exposure, respectively. This is because most of the classroom-milligauss are contributed by the many classrooms with low field levels.

Although the background incidence of leukemia in adults is higher, on average, than the incidence of leukemia in school-aged children, the number of adult staff in schools is small compared to the number of children. If EMF exposure carried the same relative risk for adults as for children, leukemia incidence attributable to school-time EMF exposure among adult staff would be about 13% that among students.

As part of the analysis in this project we estimated the background rate of 21 diseases which have been associated with EMF exposure in more than one epidemiologic or animal study.

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percentile level as that which characterizes the student desk with the highest reading.

Table S-8-2 shows the approximate annual number of cases and deaths which would be expected among California's 5.7 million public school students and 280 thousand teachers/staff, even if EMFs had no effect whatsoever. We have ranked the conditions by disability adjusted life years (DALYs) lost to death and morbidity. The DALY concept is one common approach for combining morbidity and mortality effects into a single index of disease burden. DALYs are calculated by adding the life-years lost from premature death and the years lived with disability, weighting the latter by disability weights for each disease, obtained from the World Health Organization's project to assess the severity of different diseases. (Murray and Lopez, 1996a; Murray and Lopez, 1996b) DALYs are shown in the rightmost columns of Table S-8-2. For many of the 21 untoward health outcomes, children contribute fewer deaths and cases than the fewer teachers and staff because, although students outnumber teachers and staff by at least 20 to 1, the rate of most diseases is much lower among the former.

The EMF_SCHOOL model estimates risk reductions that might result from an exposure standard. The model assumes that EMF risk is proportional to 24-hour time-weighted average magnetic field exposure and that exposure reductions achieved by an exposure standard can be converted into morbidity and mortality savings using a simple linear model (see Section 6.2 of main report). Estimated morbidity and mortality reductions from field-strength standards depend on assumptions concerning which diseases arise from EMF exposure, how steep the dose-response is, and the amount of exposure reduction resulting from the standard.

*Table S-8-2. <u>All-cause</u> (combined non-EMF and EMF) morbidity, mortality, and loss of disability-adjusted life years among students and staff in California schools from 21 conditions that have been associated with EMF exposure in more than one epidemiologic or animal study. Values are given to two significant figures, but uncertainties range from a factor of 10% for the best-known and most common conditions to 300% for the least common conditions. Conditions are listed in order of total disease burden in disability-adjusted life-years (DALYs). Cases of spontaneous abortion and perinatal mortality are assigned 75 DALYs each. See main report for details of DALY calculation.*

| **Disease** | **New cases per year** | | **Deaths per year** | | **DALYs lost per year** | |
|---|---|---|---|---|---|---|
| | Students | Staff | Students | Staff | Students | Staff |
| Spontaneous abortion | 12,000 | 1,500 | 0 | 0 | 900,000 | 110,000 |
| Low birth weight | 2,400 | 400 | 0 | 0 | 41,000 | 6,700 |
| Perinatal mortality | 280 | 46 | 0 | 0 | 21,000 | 3,500 |
| Suicide | 120 | 42 | 120 | 42 | 7,400 | 1,500 |
| Leukemia | 190 | 25 | 94 | 14 | 6,200 | 420 |
| Coronary heart disease | 5.4 | 2,100 | 0.54 | 200 | 34 | 5,300 |
| Lung cancer | 2.1 | 186 | 0 | 130 | 0.83 | 3,500 |
| Cardiac arrythmia | 58 | 32 | 5.4 | 9.8 | 350 | 2,500 |
| Brain/CNS | 140 | 19 | 36 | 15 | 2,400 | 410 |
| Alzheimers | 0 | 190 | 0 | 1.3 | 0 | 2,300 |
| Breast (f) | 0.53 | 310 | 0 | 67 | 0.21 | 1,940 |
| Non-Hodgkins lymphoma | 57 | 48 | 12 | 15 | 800 | 420 |
| Unipolar major depression | 2,700 | 900 | 0 | 0 | 450 | 150 |
| Hodgkins | 77 | 8.0 | 7.5 | 1.7 | 500 | 59 |
| Melanoma | 0 | 170 | 0 | 8.3 | 0 | 270 |
| Prostate cancer | 0 | 77 | 0.30 | 6.6 | 19 | 210 |
| ALS | 1.4 | 3.7 | 1.4 | 3.7 | 94 | 100 |
| Wlims | 12 | 0 | 0.62 | 0 | 47 | 0 |
| Breast (m) | 110 | 0.71 | 0 | 0.11 | 43 | 3.1 |
| Testicular cancer | 19 | 5.1 | 0 | 0.25 | 12 | 13 |
| Neuroblastoma | 0.097 | 0 | 0.045 | 0 | 3.3 | 0 |

Figure S-8-1 shows the estimated number of those cases that might be avoided by classroom field-strength standards if leukemia were the only disease associated with EMF exposure and if leukemia risk were proportional to time-average magnetic field exposure. These estimates of avoided leukemia cases are for the state as a whole. Given that there are roughly 7,700 schools in California, the number of leukemia cases avoided per school will be in the range of .0001-.001 cases per year per school, depending on the level of the exposure standard and the assumed relative risk of EMF exposure.

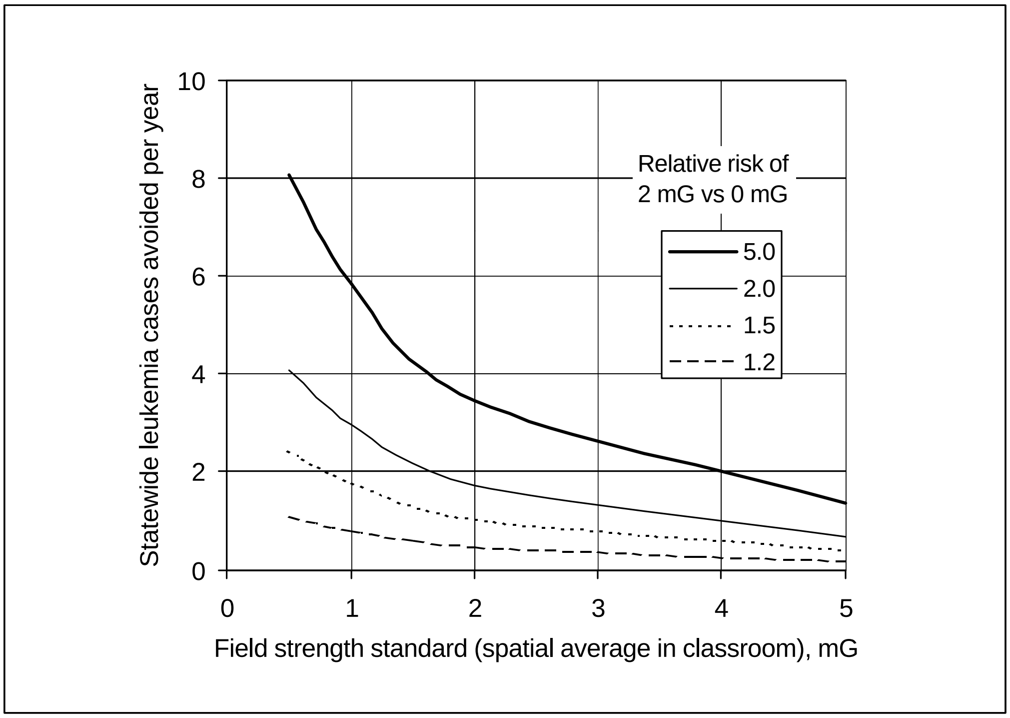


*Figure S-8-1. Leukemia cases avoided per year among all California students vs. classroom average field-strength standard and relative risk (Assumptions: degree of certainty=1, fraction close to lines= medium, mitigation efficacy=1).*

## S-8.3 *Cost of Applying Field Strength Standards*

Estimating the costs of magnetic field reduction is complicated by uncertainties in both the unit cost of source mitigation (i.e. the cost of addressing a single situation) and the number of situations that would require attention under a given field strength standard. Zaffanella and Hooper (Zaffanella and Hooper, 2000) of Enertech have estimated the unit costs of magnetic field standards applied to California schools and combined these with frequency data from their 89-school survey to estimate the statewide costs of meeting various field strength standards. Best estimates for the total costs of meeting 1 mG, 2 mG, and 5 mG standards for the average field in classrooms are $122 million, $44 million, and $15 million, respectively.[7] Uncertainties in these estimates range from +/- 20% at 1 mG to perhaps +/- 50% at 5 mG. These estimates include about $10 million for the cost of surveying and diagnosing different sources in all schools. Survey costs are the dominant portion of total cost for field-strength standards above 4 mG. Of the total costs of meeting a given classroom standard by addressing all sources, the fraction needed to address power lines

[7] These costs include the costs of surveying but do not include the option of limiting access to school areas.

ranges from 25%-33%, depending on the standard level. Although the total costs to reduce power line fields are smaller than those to reduce fields from internal sources (e.g. net currents), reducing field levels from power lines is generally more expensive per unit of population exposure reduction than reducing fields from internal sources.

Table S 8-3 shows the estimated cost per affected school and the total cost statewide for modifying various sources of EMFs so that they would comply with a 2 mG standard. The average cost per affected school for reducing fields from distribution and transmission lines is modest ($30,000-$65,000). This is because it is often not necessary to underground power lines to lower classroom fields below 2 mG. Modifying wire spacing or phasing on the existing pole or tower can often achieve this goal. If undergrounding was required for all cases in which classroom fields from power lines exceed 2 milligauss, then the average cost per affected school would increase by roughly 2-fold, and the total statewide costs of meeting the standard would increase by roughly $20 million, to a total of roughly $63 million.

To put these $100 million (or so) statewide EMF-mitigation costs into perspective, one can consider that over the several decade physical lifetime of the measures used to meet the EMF standard, the net present value of revenues taken in by California electric utilities will be several hundred billion dollars and the net present value of expenditures for California public schools will be a couple of trillion dollars.[8]

[8] Assumes 30 year lifetime of mitigation and 5% discount rate. 1997 revenues of all California electric utilities combined were $21.3 billion according to the Energy Information Administration. Expenditures for California public schools in 2000-1 totaled $78 billion according to the California Department of Education.

*Table S 8-3. Costs of meeting a 2 mG standard for the spatially-averaged magnetic field in classrooms. Costs are best estimates, based on unit cost estimates and exposure data in Zaffanella and Hooper 2000. Actual costs may differ considerably from these estimates.*

| | Source | | | | |
|---|---|---|---|---|---|
| | **Net currents** | **Electrical panels** | **Distribution lines** | **Transmission lines** | **All four** |
| Cost per affected school | $5,300 | $37,000 | $30,000 | $65,000 | $13,000 |
| Number of affected schools* | ~ 3,000 | ~ 300 | ~ 300 | ~ 200 | ~3,500 |
| Statewide total costs | $16 million | $12 million | $9 million | $13 million | $43 million |
| Statewide costs, not including survey | $8 million | $4 million | $8.3 million | $12.8 million | $33 million |
| Statewide survey costs ** | $8 million | $8 million | $0.7 million | $0.2 million | $10 million |
| Fraction of school-time EMF exposure eliminated | 20% | 1% | 4% | 3% | 29% |

* Total for all four doesn't equal sum of values for each source because some schools have average classroom fields of 2 mG from more than one source type.
** Survey costs for individual sources assume survey is dedicated to that source. Survey cost for all four sources doesn't equal sum of survey costs for each source because of economy of scope.

### S-8.4 *Cost Effectiveness of Field-Strength Standards*

Cost-effectiveness is often used as a criteria of policy merit by those who espouse the utilitarian ethical world view, which aims to achieve the most good for the most people. Cost-effectiveness is the cost of a policy divided by its benefits. In the case of EMF management programs, cost effectiveness can be measured in dollars per disability-adjusted life-year saved. A more cost-effective policy is not necessarily a less expensive policy, a policy that affects more people, or a policy with larger benefits. The most cost-effective policy is the one that produces the highest return per unit of investment. By prioritizing investments in health and safety protection by cost effectiveness, society can maximize the amount of life saving that those investments produce.

Research has shown that the cost effectiveness of actual lifesaving interventions varies over a wide range. A 1997 study by Tengs et al. (Tengs et al., 1995) of the cost effectiveness of 139 government lifesaving interventions found cases ranging from hundreds of dollars per life-year saved to tens of millions of dollars per life-year saved, with an average across all interventions of $44,000 per life-year. Using this average value, saving the life of a ten-year-old child (which on average would save 65 years of life) would be valued at $2.86 million dollars without discounting, or $650,000 with discounting at 5%.

Zaffanella and Hooper (2000) estimate the total cost of meeting a 2 mG standard to be $44 million. For this to be justified from a cost-benefit perspective, the standard would have to save the lives of 15 ten-year-olds (non discounted) over the physical lifetime of the mitigation (normally several decades). If one discounts lifesaving, then EMF exposure reduction would have to save about 70 lives over that several decade period to justify the expenditures. This represents less than a few percent of leukemia deaths among school-age children, and a much smaller fraction of deaths from all diseases possibly related to EMF exposure.

Figure S-8-2 shows the cost-effectiveness of magnetic field field-strength standards applied to different sources (net currents, electrical panels, and power lines), as a function of the level of the standard for a case in which leukemia is the only disease associated with EMF exposure. The shapes of these curves are the result of two effects. First, the fixed costs of surveying and diagnosing magnetic field sources in all schools are spread over an increasing number of sources as the field standard is made more stringent. That is, as the field standard becomes more stringent, there are more net currents, electrical panels, and power lines that need to be fixed. This effect is most pronounced for electrical panels, which have very few cases at high field levels over which to spread the surveying costs. Second, the engineering cost of mitigation itself grows rapidly with increasing field reduction requirements.

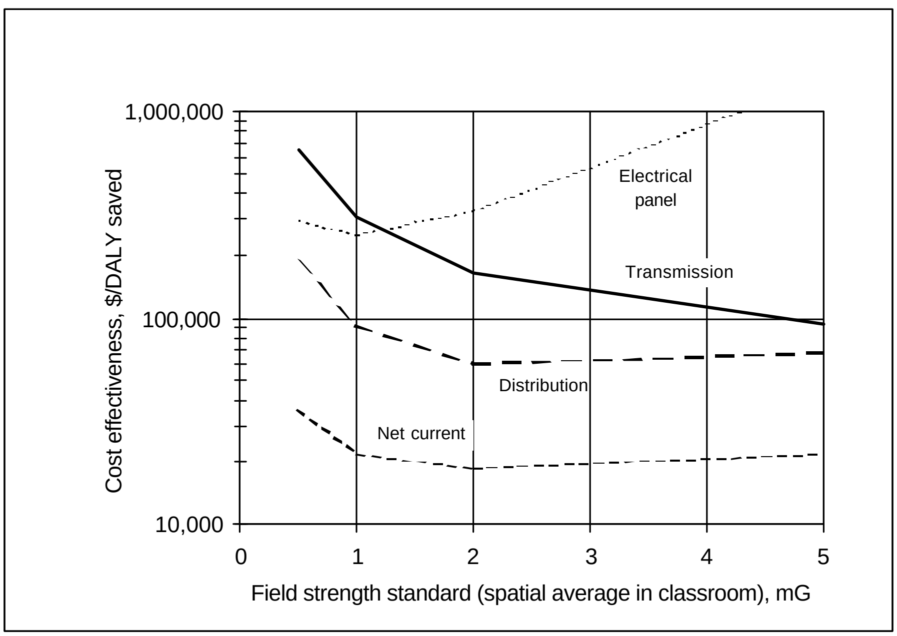


*Figure S-8-2. Cost effectiveness of field-strength standards in classrooms, assuming EMF causes only leukemia. Units: $ per disability-adjusted life-year (DALY) saved. (Assumptions: degree of certainty=1, relative risk=2, mitigation efficacy=1, fraction close to lines=medium, cost multiplier=1, discount rates=5%)*

Figure S-8-3 illustrates how the cost-effectiveness of magnetic field standards vary with the disease assumed to be caused by EMF. All other things being equal, EMF exposure reduction is likely to produce greater health savings for those diseases that have high background rates, that affect younger populations, and that have the most serious outcomes (i.e. death). The results in Figure S-8-3 assume that EMF exposure is responsible for only one disease. If EMF were associated with more than one disease, the combined cost-effectiveness of exposure reduction would be better (fewer $ per DALY saved) than the examples in Figure S-8-3

The results in Figure S-8-2 and Figure S-8-3 assume that time-average magnetic field exposure of 2 mG doubles the risk of disease. Under this assumption, cost-effectiveness estimates for net currents and distribution lines lie well within the range of cost-effectiveness found by Tengs et al. to be associated with typical government lifesaving interventions, even when only a single disease (leukemia) is considered.

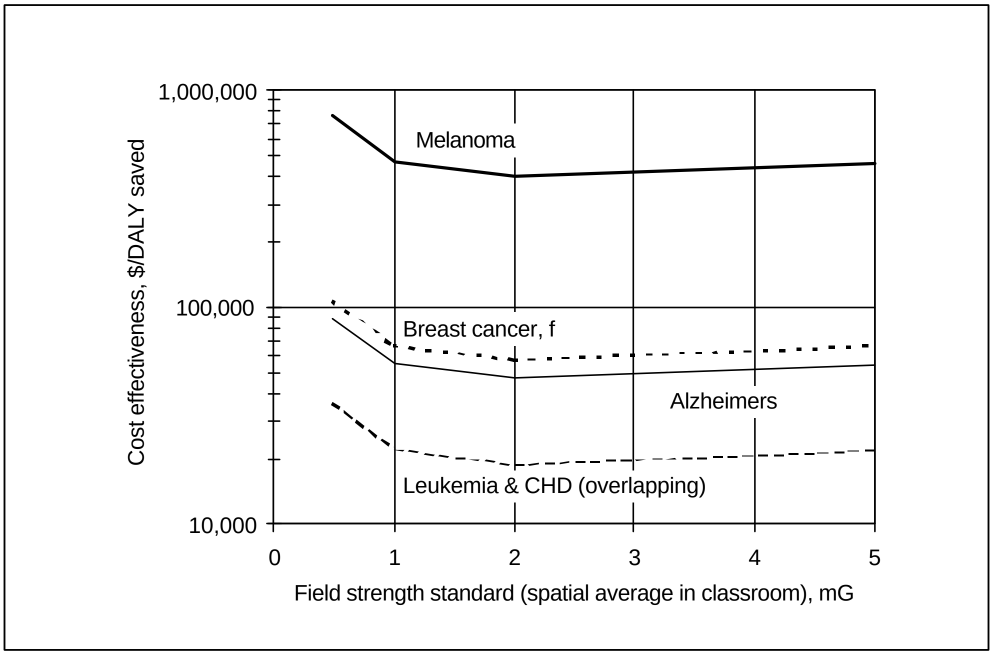


*Figure S-8-3. Cost effectiveness of field-strength standards for net currents for 5 diseases possibly associated with EMF. DALY=disability-adjusted life-year. (Assumptions: degree of certainty=1, relative risk=2, mitigation efficacy=1, fraction close to lines=med, cost multiplier=1,discount rate=5%)*

## S-8.5 *Net Benefit of Field-Strength Standards*

Net benefit is another measure of policy merit that is often used to compare policy alternatives by those who espouse the utilitarian ethical world view. The net benefits an exposure standard are defined as the monetized value of health savings[9] minus the cost of intervention.

The EMF_SCHOOL model was also used to compare the net benefits of implementing an exposure standard now compared to waiting a number of years until scientific consensus is reached on whether or not magnetic fields have any health impacts. These results, some of which are shown in Figure S-8-4 show that postponing magnetic field standards until scientific consensus is reached becomes more attractive as (i) the probability that scientists will conclude that magnetic fields are truly hazardous decreases, (ii) the relative risk of EMF-related disease decreases, (iii) the estimated time until scientists reach consensus gets shorter, (iv) the exposure standard being considered is applied to sources that are more expensive to fix than net currents, and (v) willingness to pay for risk reduction decreases. One does not need to have 100% confidence in an EMF leukemia effect for one to act now rather than wait for scientific consensus.

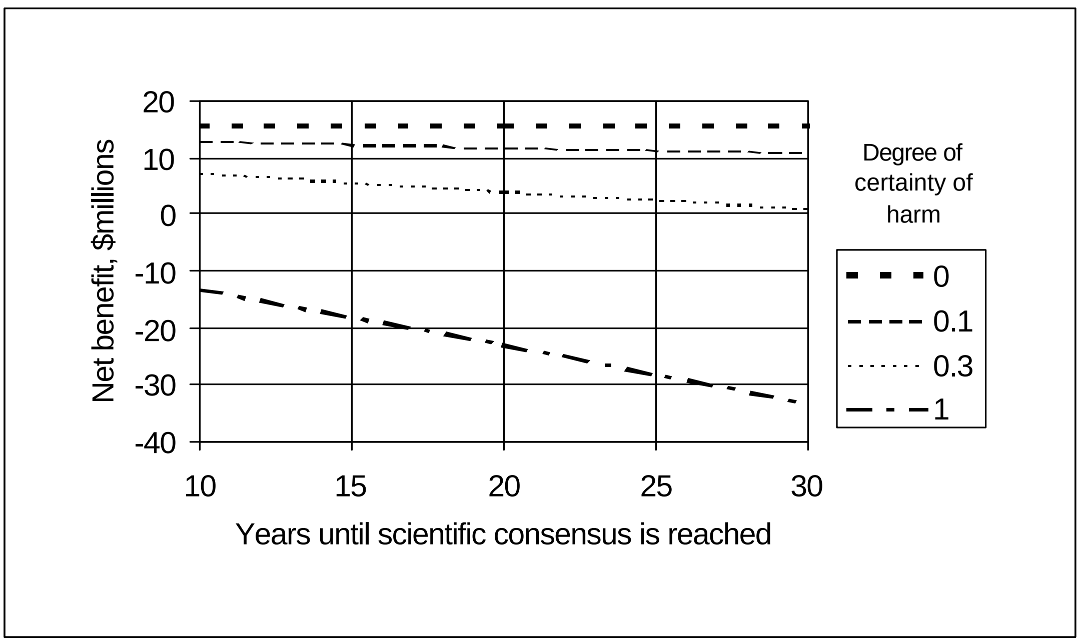


*Figure S-8-4. Net benefits of waiting to implement a 2 mG spatial average classroom standard for net currents only vs. degree of certainty that EMF is harmful and years until consensus is reached. (Assumptions: disease=leukemia only, willingness to pay=$50k, relative risk=2, mitigation efficacy=1, fraction close to powerlines=medium, cost multiplier=1)*

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[9] Reductions in EMF health impacts associated with an exposure standard are monetized (assigned a monetary value) by multiplying the health savings in disability-adjusted life years by a willingness to pay (WTP) for risk reduction. The results in Figure S-8-4 assume WTP=$50,000 per disability-adjusted life-year.

## S-8.6 *Sensitivity Analyses*

The estimated net benefits of a magnetic field exposure standard span a range from a net loss of about one hundred million dollars (for a stringent standard applied to all four sources, but yielding no health benefit) to a net gain of hundreds of millions of dollars (for a stringent standard applied to all four sources in the case that all 21 diseases are strongly associated with EMF exposure). The parameters that contribute most to this uncertainty are the diseases attributed to EMF exposure, the dose-response associated with each disease, the sources that are targeted by the policy, the value placed on saving a DALY, and the magnetic field standard itself. In Figure S-8-5 to Figure S-8-12, the net benefits of 1 mG and 2 mG field-strength standards are illustrated for both a single disease (leukemia) and all 21 diseases combined for standards that target a single source (net currents) and all four sources, across a broad range of dose-response possibilities. Of course, the chances are miniscule that all 21 diseases considered in this analysis would eventually be shown to be caused by EMF exposure. This case is included only to illustrate the sensitivity of net benefits to the number of diseases one ascribes to EMF. From these graphs, the following observations can be drawn.

For leukemia alone at relative risks noted in recent meta-analyses (Ahlbom et al., 2000; Greenland et al., 2000), an exposure standard applied to all four sources does not yield positive benefits, even for a very high degree of certainty. An exposure standard applied only to net currents, however, will yield positive net benefits for degrees of certainty above roughly 50%.

For all diseases combined, the net benefits of an exposure standard can be quite large, even when mitigation includes less cost-effective sources (e.g. transmission lines) and even for relatively low degrees of certainty and relative risks.

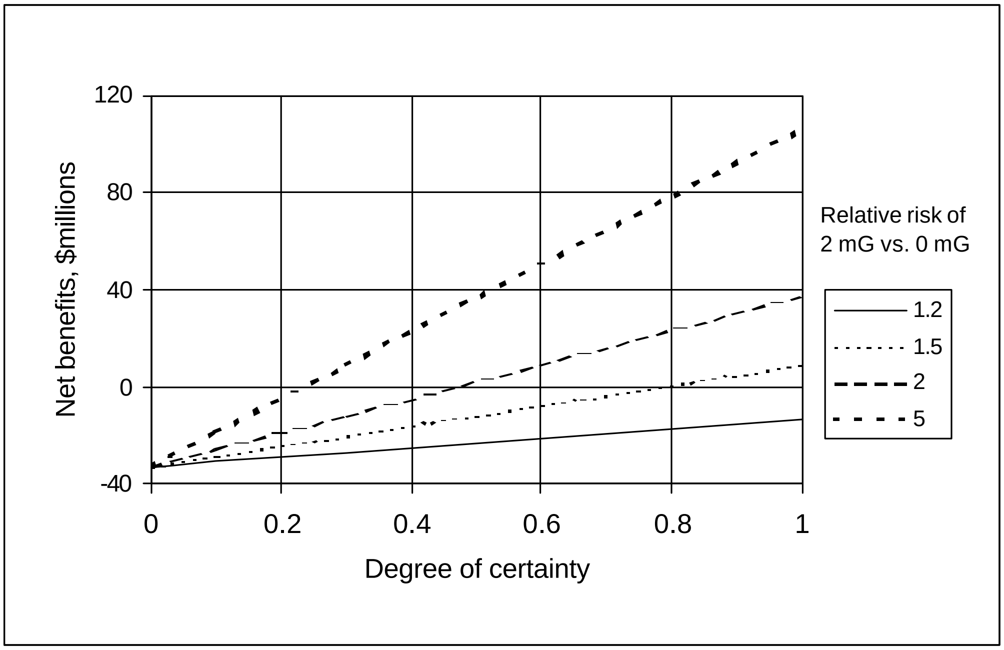


*Figure S-8-5. Net benefits of a 1 mG standard for net currents versus degree of certainty and relative risk, assuming that leukemia is the only disease associated with EMF exposure. (wtp=$50k, mit eff=1, frac close=med, cost mult=1, disc rates=5%).*

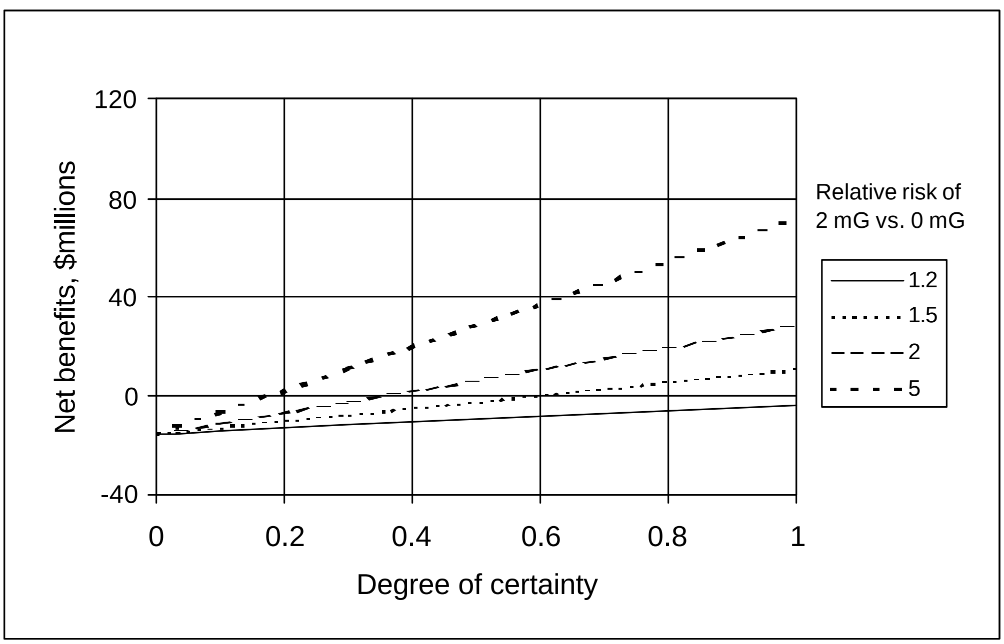


*Figure S-8-6. Net benefits of a 2 mG standard for net currents versus degree of certainty and relative risk, assuming that leukemia is the only disease associated with EMF exposure. (wtp=$50k, mit eff=1, frac close=med, cost mult=1, disc rates=5%).*

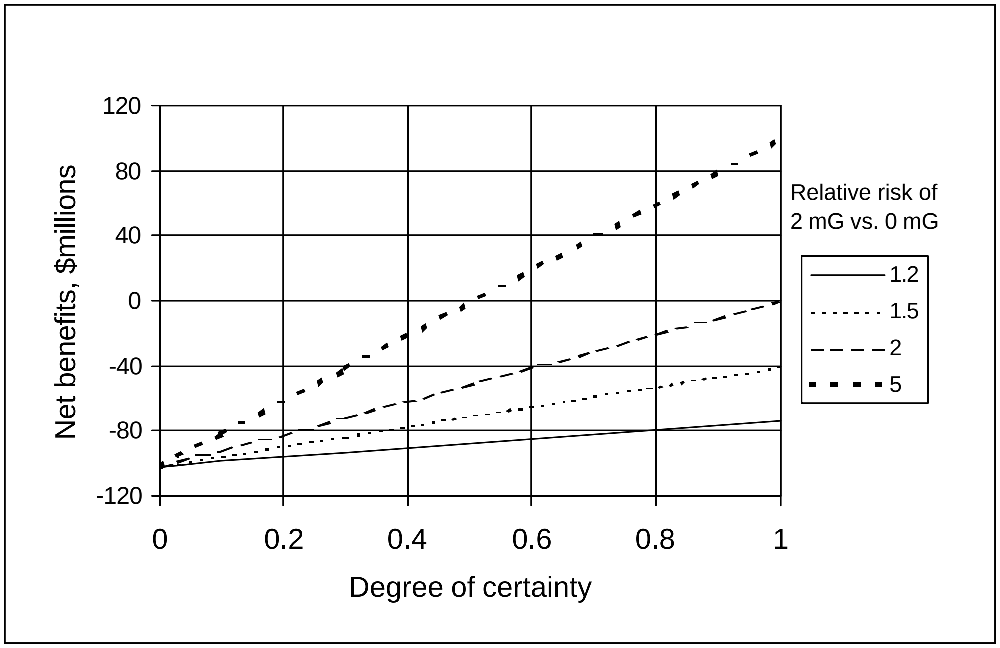


*Figure S-8-7. Net benefits of a 1 mG standard for four sources vs. degree of certainty and relative risk, assuming that leukemia is the only disease associated with EMF exposure. (wtp=$50k, mit eff=1, frac close=med, cost mult=1, disc rates=5%).*

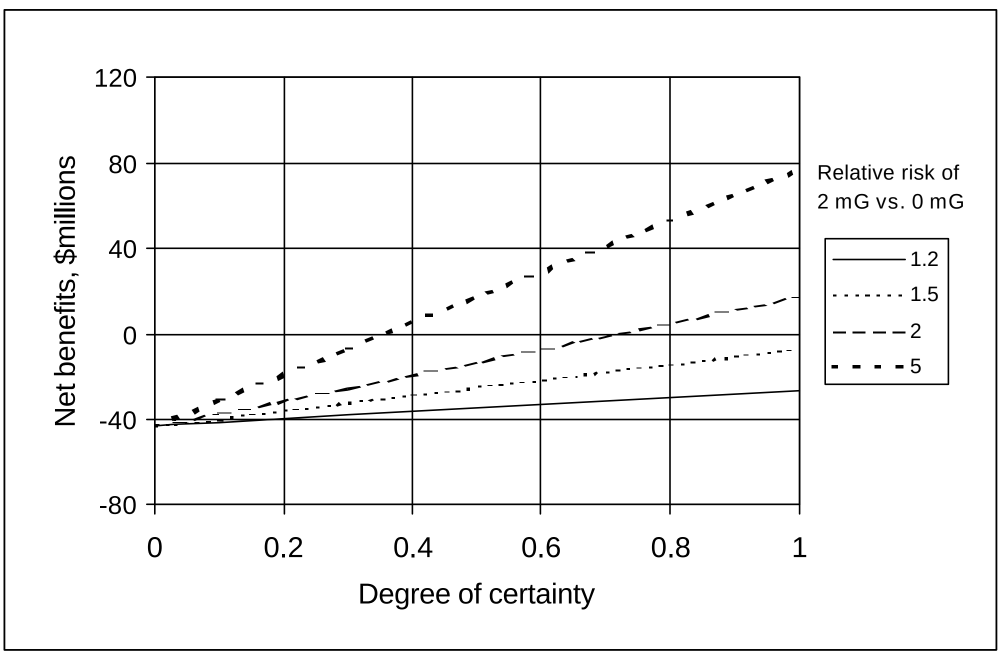


*Figure S-8-8. Net benefits of a 2 mG standard for four sources vs. degree of certainty and relative risk, assuming that leukemia is the only disease associated with EMF exposure. (wtp=$50k, mit eff=1, frac close=med, cost mult=1, disc rates=5%).*

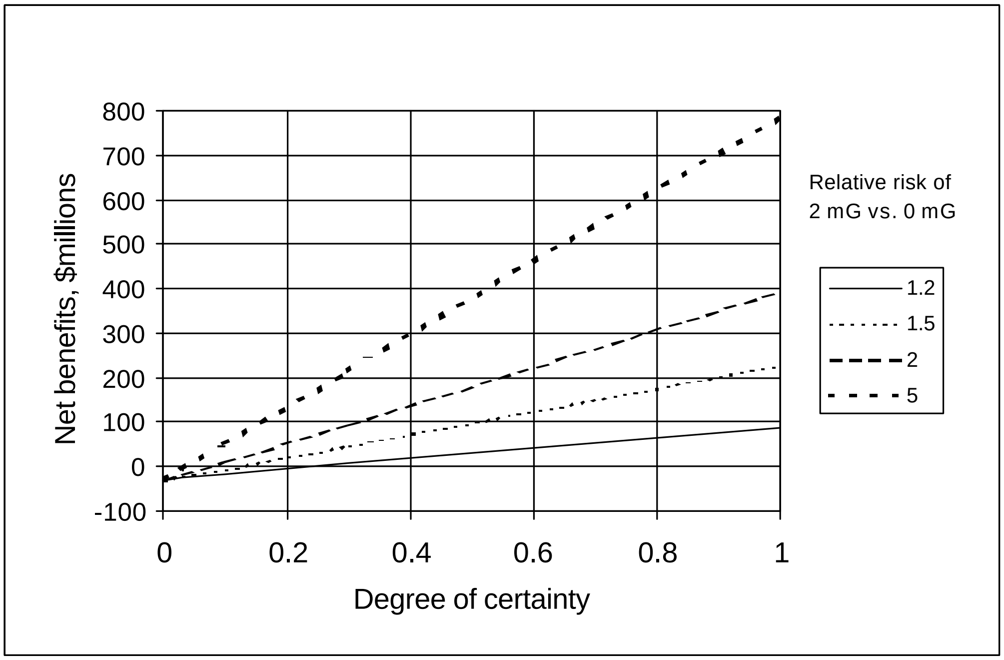


*Figure S-8-9. Net benefits of a 1 mG standard for net currents versus degree of certainty and relative risk, assuming that all 21 diseases are associated with EMF exposure. (wtp=$50k, mit eff=1, frac close=med, cost mult=1, disc rates=5%).*

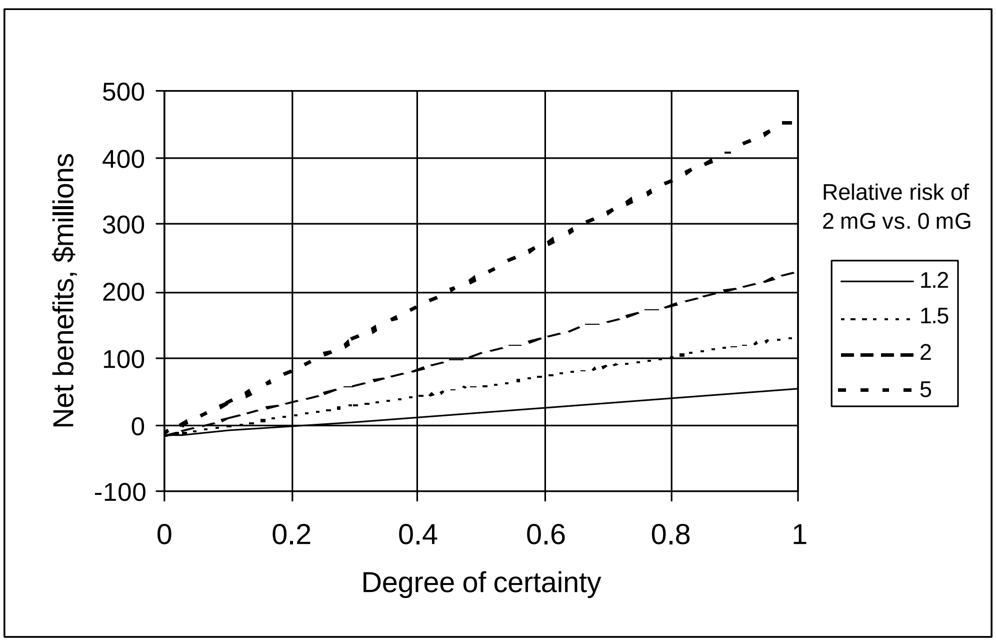


*Figure S-8-10. Net benefits of a 2 mG standard for net currents versus degree of certainty and relative risk, assuming that all 21 diseases are associated with EMF exposure. (wtp=$50k, mit eff=1, frac close=med, cost mult=1, disc rates=5%).*

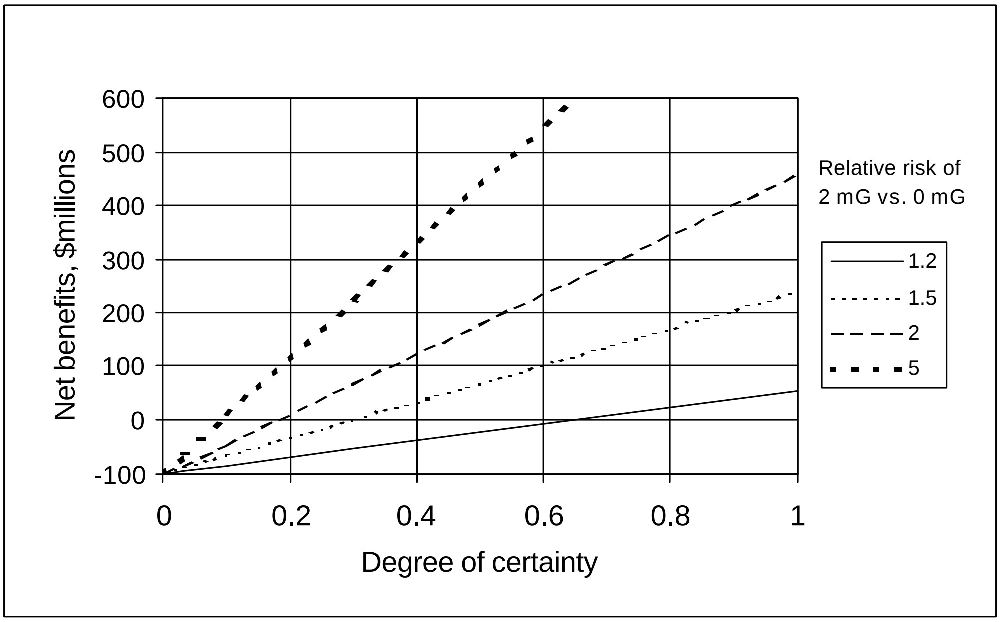


*Figure S-8-11. Net benefits of a 1 mG standard for all four sources versus degree of certainty and relative risk, assuming that all 21 diseases are associated with EMF exposure. (wtp=$50k, mit eff=1, frac close=med, cost mult=1, disc rates=5%).*

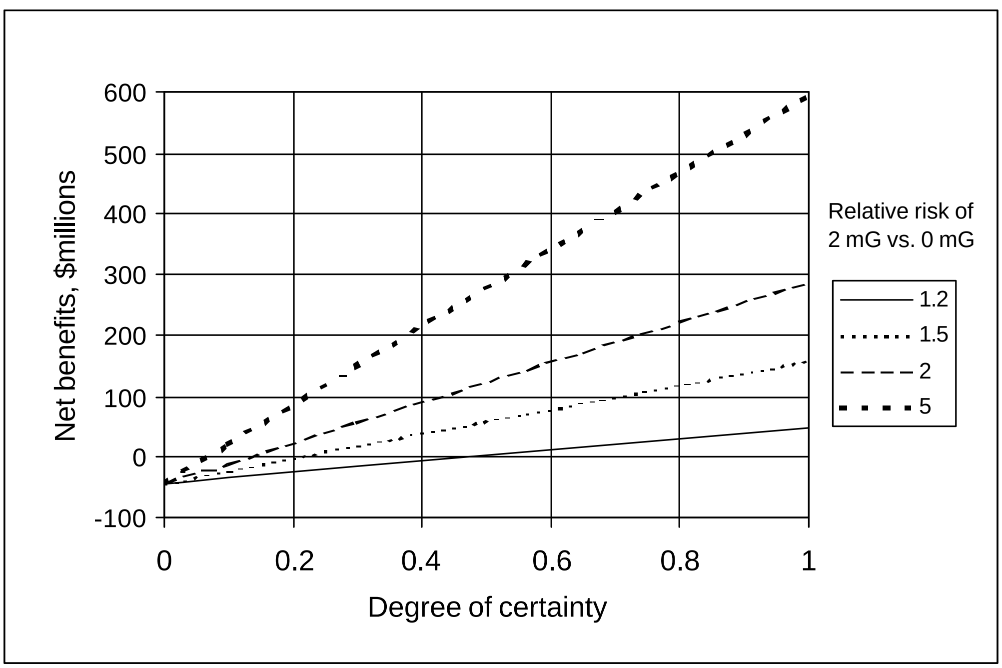


*Figure S-8-12. Net benefits of a 2 mG standard for all four sources versus degree of certainty and relative risk, assuming that all 21 diseases are associated with EMF exposure. (wtp=$50k, mit eff=1, frac close=med, cost mult=1, disc rates=5%)*

## S-9. Funding Options

The funding needs for the various policy options discussed above range from modest or even negligible for some purely procedural options to perhaps $100 million for aggressive modifications to existing school wiring and power lines near schools. Options to pay for these options include various taxes, bonds, and electric rate surcharges. Factors that need to be considered in choosing a funding option include the amount of funding required, the fairness of the distributions of who will pay and who will benefit, political feasibility, administration/enforcement costs, and the match between when the funds are needed and when they will become available.

It is challenging to identify a single source of funding that seems appropriate for addressing EMF exposure from both power lines and internal sources such as net currents and electrical panels. All electricity users are responsible for EMF exposure from transmission lines, but only schools themselves are responsible for EMF exposure from internal sources. So fairness concerns might demand that funds for address transmission line exposures at schools be raised from all electricity users, whereas funds for addressing internal sources be collected only from school users. Of course, school budgets are often funded by property taxes that are paid by all property owners, not only those who have children in school. So fairness concerns may not trump other considerations such as ease of implementation and enforcement.

Table S- 9-1 presents a number of funding options with brief descriptions of their characteristics.

*Table S- 9-1. Possible sources of funding for EMF policy options.*

| Option | Electricity tax or surcharge on electricity rates | Transmission line right-of-way tax or revenue tax | Sales tax surcharge | Additional property (school) tax |
|---|---|---|---|---|
| **Who pays** | Electricity users in proportion to their electricity use | Utilities in proportion to the miles of right of way that they operate or their total revenue | Everyone in proportion to their consumption | Property owners in proportion to their property value |
| **Sources** | Transmission and distribution lines | Transmission lines only | All | All |
| **Progressiveness** | Rich pay more because they use more electricity | Rich pay more because they use more electricity | Rich pay more because they consume more | Rich pay more because they own more property |

In addition to these sources of possible revenue, bonds may be used to spread out payments for a lump sum investment in EMF mitigation. By issuing a bond, the funds needed to fund a particular EMF policy could be collected over many years, rather than all at once.

## S-10. Summary and Conclusions

Two decades of epidemiologic research suggest that chronic exposure to power-frequency magnetic fields of several milligauss may elevate leukemia risk. The various expert scientific bodies that have reviewed this evidence have issued no quantitative judgments of the probability that these epidemiologic results reflect a causative link between magnetic fields and leukemia. To caricature the conclusions of these many expert bodies: "There is no conclusive evidence that EMF exposure is harmful." Such pronouncements, while true, are not very useful to policy makers, who may decide to take protective actions when evidence is short of conclusive. Evidence for an EMF connection to other deleterious health conditions is much more limited than for leukemia, but the high background rates of some of these other conditions mean that even limited evidence might be important.

Using data from the Enertech 89-school survey, we have described the EMF environment in California schools and identified those sources that contribute most to either population or individual EMF exposure. Of the ten major types of EMF sources in schools, Enertech's data show that net currents are by far the largest contributor to both population average field levels and individual exposures to strong fields (e.g. > 5 mG). Transmission lines, which were the focus of much of the early concern about EMF in schools, contribute surprisingly little (about 2%) to population-average field levels in classrooms. Cases in which transmission lines are located close enough to school buildings to cause significantly elevated classroom fields are rather rare.

The costs of remediation differ greatly from source to source (Zaffanella and Hooper, 2000). Whereas a classroom affected by magnetic fields from a net current source might be fixed for less than $100, the cost of eliminating transmission line fields in a classroom might be 1,000 times as large. Thus, for a given statewide remediation budget, significantly more magnetic field reduction can be achieved by focusing only on those sources that are cheapest to eliminate. The downside of this strategy is that exposures would not be reduced for thousands of individuals in unusually strong magnetic fields.

The costs of reducing magnetic field levels in classrooms increases sharply as the field reduction target is lowered. The cost of meeting an average classroom field of 1 mG, for instance, is 2-3 times that of meeting a 2 mG target. The statewide costs of reducing magnetic field levels in schools include both the costs of a survey to map field levels and identify sources, and the costs of the labor and material needed to effect field reductions. Zaffanella and Hooper estimate the statewide survey costs to be roughly $10 million

($1400 per school). The statewide costs of modifying power lines and internal sources depend on the reduction target and on whether field strengths are to be lowered in outdoor areas as well as in classrooms. The statewide cost of meeting a 1 mG standard for average classroom field level is estimated to be about $100 million if both power lines and internal sources are modified, excluding the survey cost. The statewide costs of treating only net current classrooms exceeding 1 mG would be about $32 million. As these field reductions extend throughout the physical lifetime of school facilities, such expenditures would amount to less than one dollar per year for each California student.

The health benefits of EMF exposure reduction are unknown, although it is clear that whatever effects might exist are not easy for scientists to find. Past epidemiologic studies have turned up hints of associations between EMF and a number of diseases, but, according to a 1998 expert panel assembled by National Institute of Environmental Health Sciences, leukemia is the only disease for which evidence is sufficient to judge an EMF association to be "possible." In this study, we have conducted some "what if" exercises to estimate possible health benefits under a variety of possible scenarios involving 21 different diseases and different strengths of dose-response relationship.

We have estimated possible reductions in both mortality and disease burden, the latter expressed as savings in disability-adjusted life years, or DALYs. If all 21 diseases considered in the analysis were equally likely to be associated with EMF, and had similar relative risks at a given EMF exposure, we find that mortality savings from EMF exposure reduction would be greater among older adult staff than among students. This is because of the high background rates of diseases of older ages such as heart disease and lung cancer. If we consider reduction of disease burden (DALYs) rather than reduction of mortality, however, the savings among the student population and younger adults becomes prominent. In particular, if untoward pregnancy outcomes are assigned 75 life-years per case avoided, then reductions in spontaneous abortion alone would contribute almost 90% of the total savings in disease burden among students and staff. Of course, opinions vary on the number of lost life-years that should be assigned to a spontaneous abortion. Aside from untoward pregnancy outcomes, the conditions contributing most to the savings in disease burden would be suicide, leukemia, heart disease, and lung cancer.

Of course, the epidemiologic evidence for an EMF connection differs greatly for the 21 diseases we consider. Childhood leukemia is the disease with the most epidemiological evidence for an EMF link. Among California school children, there are about 100 deaths per year from leukemia. In a recent analysis of 12 studies of magnetic field exposure and childhood leukemia, Greenland et al. (Greenland et al., 2000) conclude that if residential magnetic field exposures have any effect at all, they might be responsible for roughly 3% of all childhood leukemia cases in the U.S.. Since students spend less than 20% of the time in school that they spend at home, and since EMF environments at school and home are similar, a rough estimate of avoidable leukemia deaths from eliminating all EMF exposure in schools is about 100x3%x20%

= 0.6 deaths/yr. Of course, it is impractical to eliminate all EMF exposure from schools. If only EMF exposures above 2 mG were eliminated, for instance, then number of leukemia deaths avoided would be about 0.15 deaths/yr (assuming that EMF risk is proportional to time-weighted average exposure). If, as the evidence in Greenland et al. suggest, the 1.2 deaths/yr arise from exposures above 3 mG, then the number of deaths per year prevented by a 2 mG standard might be closer to the 0.6 deaths per year.

If existing epidemiologic evidence for an EMF-leukemia link turns out to be spurious, then none of the childhood leukemia cases in California school children can be eliminated by reducing EMF exposure. On the other hand, if other diseases besides leukemia turn out to be influenced by EMF exposure, then the above estimates of avoidable morality would rise. If, as with leukemia, EMF were to account for 3% of the baseline rate of other diseases (excluding miscarriages), then the avoidable mortality and morbidity from school-time EMF exposure would be about ten times larger than if EMF caused only childhood leukemia.

Despite the modest savings in disease burden if leukemia were the only EMF-related disease, the cost-effectiveness of some EMF remediation measures can still be favorable compared to that of other life-saving interventions that society undertakes. If the EMF leukemia risk were certain, the cost-effectiveness of a statewide program to eliminate net current exposures exceeding 2 mG in existing schools, for instance, would be about $20,000 per life-year saved (assuming relative risk levels reflected in existing epidemiology). The cost-effectiveness of eliminating net currents might be somewhat better than this if one considers the reduction in the risks of electric shock, fire, and equipment damage that more widespread compliance with the National Electrical Code would convey.

Some EMF reduction measures are much less expensive when applied to new schools compared to existing ones. Avoiding net current sources by stringent design specifications or detecting and fixing net currents at the time of building construction, for instance, can be done at a fraction of the cost of repair in existing schools because the wiring is so much more accessible at the time of construction. Likewise, the position of electrical panels and high-current conduits can be modified at the time of building design at very little cost compared to the cost of shielding the panel once it is installed.

Different systems of justice have very different implications for managing EMF exposure in schools. Few people are strict adherents to utilitarianism, libertarianism, or social justice principles. In any given context, most people subscribe to some hybrid of the three. Thus, policy makers might want to consider EMF policies that combine cost-effectiveness and equity concerns. Choosing a field strength standard based on the population average cost-effectiveness would be one such alternative.

Should EMF hazards be addressed at all, given that there are other unmitigated school risks that are known with certainty, and that could be reduced at modest cost? In public policy, one can almost always find more cost-effective opportunities in domains outside the one under consideration. Often, such arguments have limited practical appeal, because the authority of the agency involved does not extend to those outside domains. For instance, the most significant non-EMF risks to school children are from traffic accidents while commuting to and from school. But most school authorities have little or no jurisdiction over traffic safety. Under current legislation, it is difficult to imagine what institutions would have the authority to comprehensively manage the diverse set of all school risks. Some subset of school risks could be identified, however, that would fall under the control of the school district.

Principles of justice apply not only to how the benefits of EMF exposure reduction should be distributed but also to who should pay for any statewide mandate. Given the different categories of ownership and consent associated with different EMF sources, different funding mechanisms might be appropriate for different sources. School (property) taxes, for instance, might be used to address risks from sources within schools (e.g. net currents), whereas a surcharge on electricity rates might be used to address EMF exposures from power lines. Whether either or both are needed, of course, will depend on policy makers' judgments concerning whether the costs of exposure reduction are commensurate with the benefits.

Future scientific research will slowly reduce uncertainties concerning what diseases, if any, are associated with EMF exposure and what measures of exposure best predict risk. It is likely, however, that significant scientific uncertainties will remain for decades to come. If one believes that consensus on EMF hazard is not likely to occur within the next 10-20 years, Figure S-8-4 implies that mitigation measures taken today can still be cost-effective if one believes that there is at least a 50% chance that the leukemia-EMF association is real.

Even if scientists were all to agree that EMF exposure is hazardous, issues of how much to pay for reducing EMF exposures, who should pay, and how to balance cost-effectiveness and equity/fairness concerns are ultimately value issues on which opinions naturally vary. The information and alternative policy framings presented in this document provide some boundaries within which these value judgments can be exercised.

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